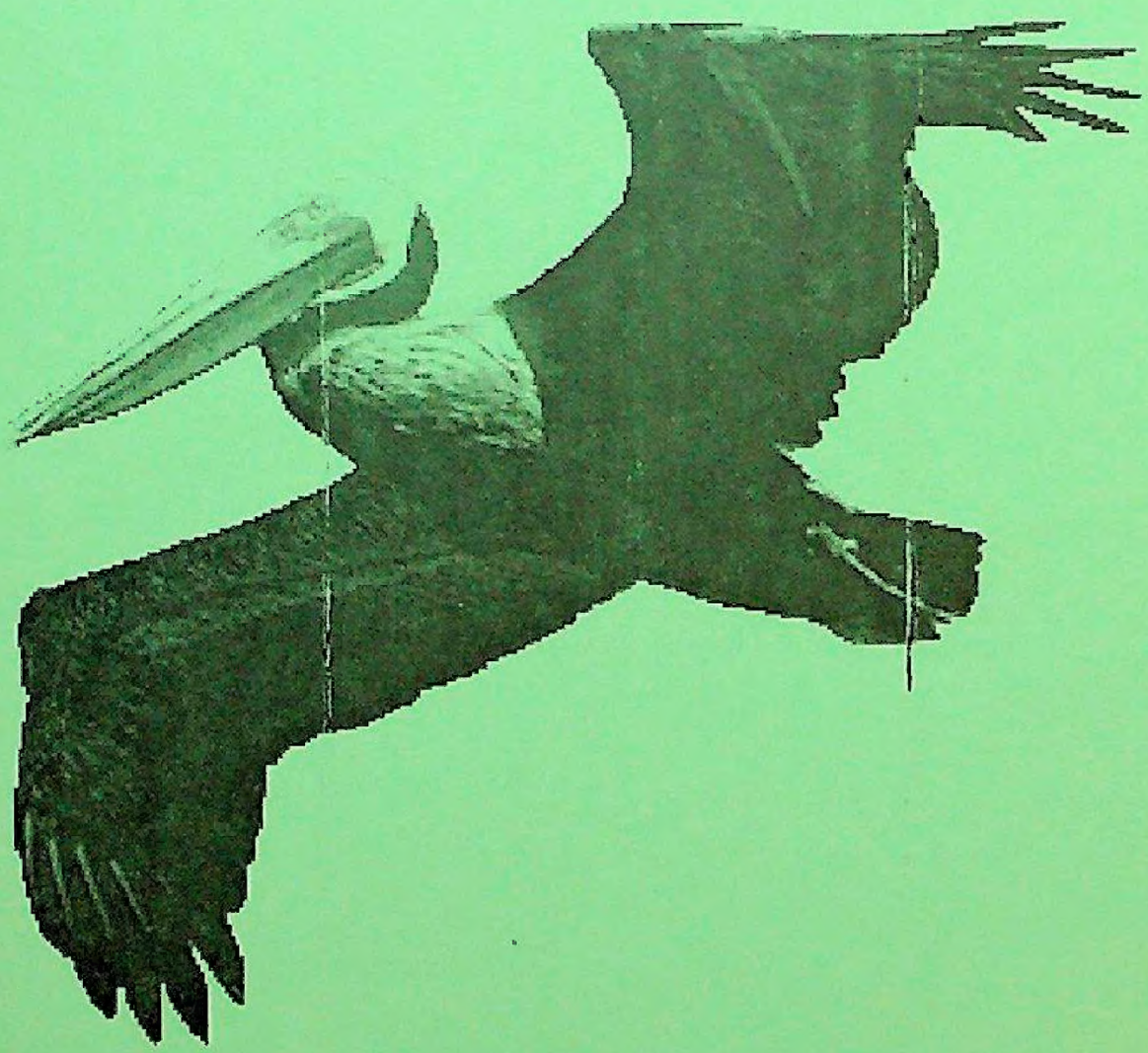
CALIFORNIA FISH and GAME

"CONSERVATION THROUGH EDUCATION"

VOLUME 86 SUMMER 2000 NUMBER 3



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Please direct correspondence to:

David W. Kohlhorst or James J. Orsi
Co-Editors-in-Chief
California Fish and Game
4001 North Wilson Way
Stockton, California 95205-2486
e-mail: dkohlhor@delta.dfg.ca.gov
jorsi@delta.dfg.ca.gov

CALIFORNIA FISH AND GAME

VOLUME 86 SUMMER 2000 NUMBER 3

Published Quarterly by

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DEPARTMENT OF FISH AND GAME
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California Fish and Game 86(3):159-174 2000

MINERAL CONTENT OF SONORAN PRONGHORN FORAGE

LISA M. FOX[1], PAUL R. KRAUSMAN, MICHAEL L. MORRISON[2],
Wildlife and Fisheries Program
The School of Renewable Natural Resources
The University of Arizona
Tucson, Arizona 85721
e-mail: Lfox@fishgame.state.ak.us

TED H. NOON
Veterinary Science and Microbiology
The University of Arizona
Tucson, Arizona 85721

Our objective was to determine the mineral content of forage species available for Sonoran pronghorn, *Antilocapra americana sonoriensis*, on the Cabeza Prieta National Wildlife Refuge (CPNWR) in southwestern Arizona. We measured vegetation abundance at 2 sites within Sonoran pronghorn range from June 1995 to May 1996 using the dry-weight-rank and comparative yield methods. We determined plant mineral contents for forage species and for species not consumed by pronghorn by collecting, freezing, drying, and analyzing vegetation samples for up to 15 species over 5 seasons. Quantities of minerals present in forage species used by pronghorn showed slight variability by site or season, and were not different in non-forage species. We constructed theoretical diet models for pronghorn based on published literature and our field data. We used the models to describe dietary intake of plant dry matter and minerals by pronghorn with and without selective use of forage. We compared predicted mineral intake by pronghorn to published requirements for domestic sheep. Diets consumed by pronghorn using plants available on the CPNWR were deficient in sodium, phosphorus, copper, zinc, and selenium.

INTRODUCTION

Sonoran pronghorn, *Antilocapra americana sonoriensis*, inhabit the Sonoran Desert in southwestern Arizona and western Sonora, Mexico (Goldman 1945). They are the smallest of 5 subspecies of pronghorn (O'Gara 1978) and were listed as an endangered subspecies in 1967 by the U.S. Fish and Wildlife Service. Although other subspecies of pronghorn (i.e., American pronghorn, *A. a. americana*; Mexican pronghorn, *A. a. mexicana*; and Oregon pronghorn, *A. a. oregona*) have partially

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[1] Current address: Yukon Charley Rivers National Preserve, P.O. Box 167, Eagle, Alaska 99738.

[2] Current address: Department of Biological Sciences, California State University, Sacramento, California 95819.

recovered from population declines in the early 1900s (Einarsen 1948; Yoakum 1986, 1994), the peninsular pronghorn, *A. a. peninsularis*, of Baja California and the Sonoran pronghorn have not (Yoakum 1986, Yoakum et al. 1996). In 1994, 250 Sonoran pronghorn were estimated to exist in Arizona and 310 in Mexico (Thompson-Olais[3] 1994).

Historically, over 700 Sonoran pronghorn ranged from eastern California to central Arizona and central Sonora, Mexico and from Hermosillo, Mexico north to the Altar Valley and the Tohono O'Odham Reservation in Arizona (Nelson 1925, Wright and deVos[4] 1986). Present range of Sonoran pronghorn extends from near Yuma, Arizona east to central Arizona, south to near Caborca, Mexico, and west to the Gulf of California (Wright and deVos[4] 1986, Yoakum et al. 1996). Causes for range constriction and past population declines of Sonoran pronghorn are unknown, but may be related to the elimination of perennial water sources (Wright and deVos[4] 1986).

Past research on Sonoran pronghorn has focused on population surveys (AGFD[5,6,7] 1978, 1979, 1981; Wright and deVos[4] 1986; Snow[8] 1994; Hervert et al.[9] 1995), and distribution (Nelson 1925, Carr[10] 1972, AGFD[11] 1985, Thompson-Olais[3]1994), but information about dietary components is limited (Carr[12, 10] 1970, 1972; AGFD[7] 1981;

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[3] Thompson-Olais, L.A. 1994. Sonoran pronghorn recovery plan revision. Draft report, U.S. Fish and Wildlife Service, Region 2, Albuquerque, New Mexico, USA.

[4] Wright, R.L. and J.C. deVos Jr. 1986. Final report on Sonoran pronghorn status in Arizona. Arizona Game and Fish Department, Phoenix, Arizona, USA.

[5] AGFD. 1978. Sonoran pronghorn investigations. *In*: Arizona big game investigations. Federal Aid to Wildlife Restoration Project W-53-R-28. Arizona Game and Fish Department, Phoenix, Arizona, USA.

[6] AGFD. 1979. Sonoran pronghorn investigations. *In:* Arizona big game investigations. Project W-53-R-29, Federal Aid to Wildlife Restoration. Arizona Game and Fish Department. Phoenix, Arizona, USA.

[7] AGFD. 1981. The Sonoran pronghorn. Federal Aid to Wildlife Restoration Project W-53-R, Special Report 10. Arizona Game and Fish Department, Phoenix, Arizona, USA.

[8] Snow, T.K. 1994. Sonoran pronghorn aerial survey summary 1992–1994. Technical Report 51, Nongame and Endangered Wildlife Program, Arizona Game and Fish Department, Phoenix, Arizona, USA.

[9] Hervert, J.M., B. Henry, and M. Brown. 1995. Sonoran pronghorn population monitoring: Progress report. Technical Report 98, Nongame and Endangered Wildlife Program, Arizona Game and Fish Department, Phoenix, Arizona, USA.

[10] Carr, J.N. 1972. Endangered species investigation: Sonoran pronghorn. Arizona Game and Fish Department, Phoenix, Arizona, USA.

[11] AGFD. 1985. Interim report on the Sonoran pronghorn antelope (*Antilocapra americana sonoriensis*) October 1983–March 1985. Arizona Game and Fish Department, Phoenix, Arizona, USA.

[12] Carr, J.N. 1970. Endangered species investigation: Sonoran pronghorn. Federal Aid in Wildlife Restoration Progress Report, Project W-53-R-20, Arizona Game and Fish Department, Phoenix, Arizona, USA.

Hughes and Smith[13] 1990; Hughes[14] 1991). Numerous researchers have investigated American pronghorn diet and nutritional content of forage (e.g., Schwartz et al. 1977, Roebuck et al. 1982, Yoakum 1990), but the mineral content of Sonoran pronghorn forage is unknown.

Nutritional requirements, availability of nutrients in forage, and bioavailability of nutrients are essential to diet assessment for wild herbivores (Ammerman et al. 1995). Wildlife nutrition studies have advanced considerably in describing the dietary requirements and nutritional intake of wild herbivores (Swift et al. 1980, Mould and Robbins 1981, Hobbs 1989). Some studies describing herbivore use of mineral licks or soil components have been conducted (Pletscher 1987, Arthur and Gates 1988, Dierenfeld and Jessup 1990); however, overall mineral requirements for wild herbivores and their availability in forage have rarely been addressed.

Fifteen minerals are essential for domestic sheep (NRC 1985). Of these, 7 are considered major mineral constituents: sodium, chlorine, calcium, phosphorus, magnesium, potassium, and sulfur. The other 8 are trace elements: iodine, iron, molybdenum, copper, cobalt, manganese, zinc, and selenium. We used mineral requirements for domestic sheep as comparison values because the data were readily available, domestic sheep have high dietary overlap with pronghorn on western ranges (Buechner 1950, Schwartz and Nagy 1976, Beasom et al. 1982), and domestic sheep and pronghorn have similar water requirements (Altman and Dittmer 1966, Wesley et al. 1970). Our objectives were to determine the mineral content of forage in Sonoran pronghorn range in southwestern Arizona and to predict pronghorn intake rates for 11 minerals.

STUDY AREA

The Growler Valley (32°31'N, 113°17'W) is the core of Sonoran pronghorn range in the United States (Thompson-Olais[3] 1994). We selected 2 study areas based on distribution of pronghorn, availability of vegetation, access to the sites, and permission to use the areas. The Agua Dulce study site is located in the Agua Dulce Mountains at the southern end of Growler Valley (Fig. 1), Cabeza Prieta National Wildlife Refuge (CPNWR) in Pima County, Arizona. The Charlie Bell site is located 75 km north of Agua Dulce, on the bajada (a long outwash slope at the base of a mountain range) west of the Growler Mountains. Both sites are approximately 20 km^2 (Fig. 1), but the Agua Dulce study site is slightly more mesic than the Charlie Bell site (T.L. Cutler, University of Arizona, unpublished data).

Growler Valley is composed of broad alluvial valleys interspersed with steep, block-faulted mountain ranges. Elevations range from about 100 to 1,200 m. Average annual precipitation is 13 cm and occurs primarily from July to September

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[13] Hughes, K.S. and N.S. Smith. 1990. Sonoran pronghorn use of habitat in southwest Arizona. Unit Project 14-16-009-1564 RWO 6, Final Report. Arizona Cooperative Fish and Wildlife Restoration, Tucson, Arizona, USA.

[14] Hughes, K.S. 1991. Sonoran pronghorn use of habitat in southwest Arizona. M.S. Thesis, The University of Arizona, Tucson, Arizona, USA.

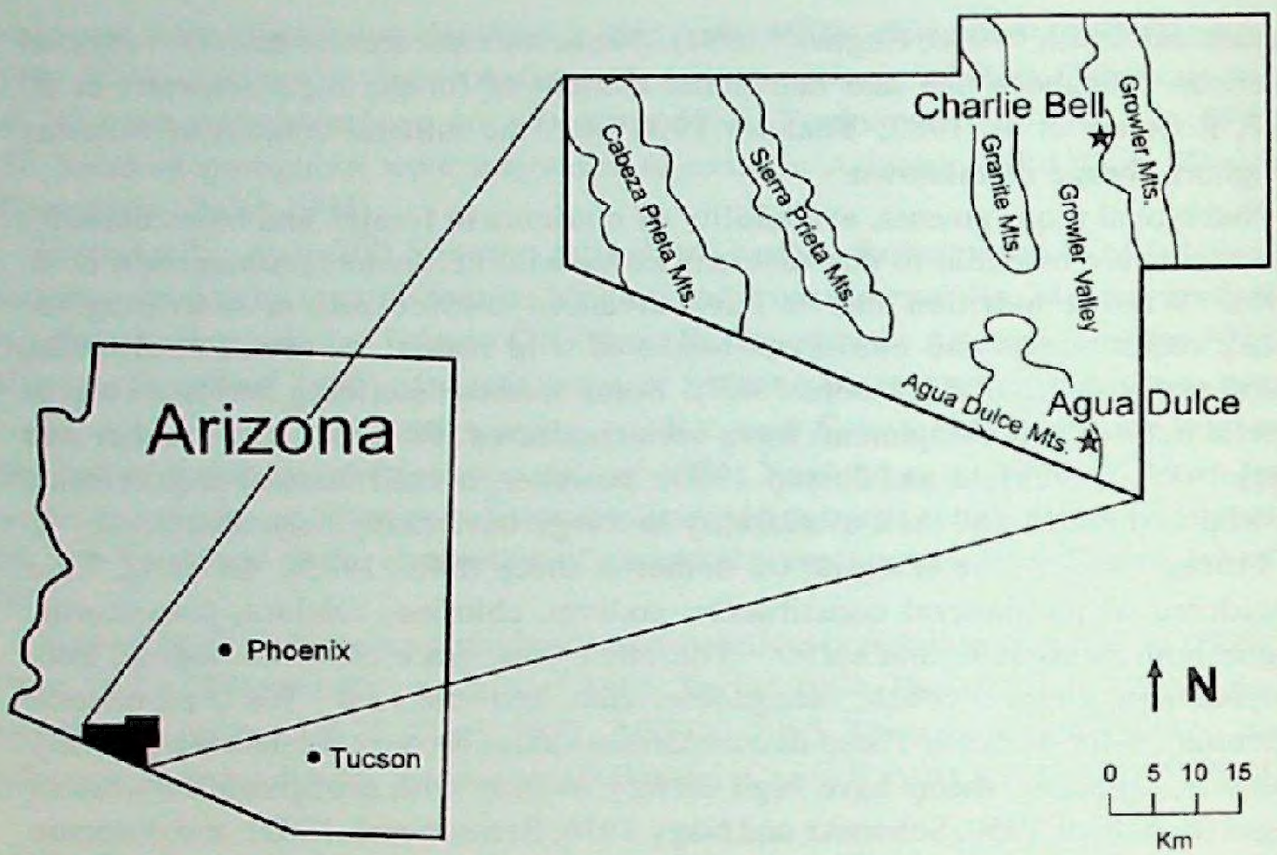

Figure 1. Location of 2 Sonoran pronghorn study sites on the Cabeza Prieta National Wildlife Refuge, southwestern Arizona, 1995–1996.

and December to February (Brown 1994). Average temperatures range from 19 to 32°C and maximum temperatures often approach 50°C during July and August (Sellers and Hill 1974).

Study sites are composed of the mixed scrub series of the Lower Colorado River Valley and Arizona Upland subdivisions of the Sonoran desert scrub vegetation community (Brown 1994). The mixed scrub series of the Lower Colorado River Valley subdivision (Brown 1994) is composed primarily of creosote bush, *Larrea tridentata*; and white, *Ambrosia dumosa*, or triangle-leaf bursage, *A. deltoidea*, on the flats, interspersed with ironwood, *Olneya tesota*; blue paloverde, *Cercidium floridum*; and mesquite, *Prosopis* spp., along washes or around playas. Washes support chuparosa, *Beloperone californica*; desert honeysuckle, *Anisacanthus thurberi*; canyon ragweed, *Ambrosia ambrosioides*; catclaw acacia, *Acacia greggii*; burrobrush, *Hymenoclea* spp.; Anderson's thornbush, *Lycium andersonii*; and desert broom, *Baccharis* spp. The Arizona Upland subdivision is composed primarily of blue paloverde; foothill paloverde, *C. microphyllum*; ironwood; mesquite; catclaw acacia; ocotillo, *Fouquieria splendens*; creosote bush; and white and triangle-leaf bursage. Other common plants include limberbush, *Jatropha cuneata*; range ratany, *Krameria parvifolia*; fairy feather duster, *Calliandra eriophylla*; and desert lavender, *Hyptis emoryi*. Cacti include staghorn cholla, *Opuntia versicolor*; chain-fruit cholla, *O. fulgida*; buckhorn cholla, *O. acanthocarpa*; teddy bear cholla, *O. bigelovii*; desert Christmas cactus, *O. leptocaulis*; pencil cholla, *O. arbuscula*; saguaro, *Cereus*

gigantea; organ pipe cactus, *C. thurberi*; fish-hook pincushion, *Mammillaria microcarpa*; and barrel cactus, *Ferocactus wislizenii*.

METHODS

We sampled the abundance of plant species on 600 (200 in flats and 400 in washes) 1-m^2 plots (Daubenmire 1959, Higgins et al. 1994) placed at 10-m intervals along 500-m line transects during each of 5 seasons (June–July, August–September, October–November, February–March, April–May) from June 1995 to May 1996. Sampling was prohibited during December and January due to federal land closures. We determined transect origins from a grid of each study area using a random numbers table and determined the direction of each transect by spinning a compass dial. Measurements for each plot included ocular estimates of quadrat yield and species composition using the comparative yield (Haydock and Shaw 1975) and dry-weight-ranking methods ('t Mannetje and Haydock 1963, Friedel et al. 1988). We used these methods to estimate plant species abundance because they were quicker and easier than using exact percentages and are appropriate for sampling desert vegetation (Ruyle[15] 1990, Mazaika and Krausman 1991, Mazaika et al. 1992). We harvested 30 1-m^2 plots for double-sampling calibrations (Higgins et al. 1994) at each study site (1 harvested/20 ranked). Vegetation from harvested plots was weighed to the nearest 0.1 g, dried at 55°C for approximately 4 days, and reweighed on a digital electronic scale. We calculated vegetation biomass (kg/ha dry weight) for creosote flats and washes and for each site and season following procedures outlined by 't Mannetje and Haydock (1963), Haydock and Shaw (1975), and Ruyle[15] (1990).

We collected and analyzed samples of forage and non-forage species for mineral content. Plant species consumed by pronghorn and selected for analysis were determined from previous diet studies of Sonoran pronghorn (AGFD[7] 1981, Hughes and Smith[13] 1990, Hughes[14] 1991) and the present availability of plants. Plant species collected varied during the calendar year to allow for changes in pronghorn diets, which change throughout the year with vegetation abundance (Yoakum 1990).

At Agua Dulce, we sampled 12 plant species for water, nutrient, and mineral content in February-March, 11 in April–May, 10 in June–July, 12 in August–September, and 12 in October–November. At Charlie Bell, we sampled 9 plant species for water and nutrient content in February–March, 9 in April–May, 9 in June–July, 9 in August–September, and 10 in October–November. For both sites combined, we sampled 15 species for analysis each season.

We hand-clipped samples of all forage and non-forage plants available 4 times over 24 hours at both study sites during each sampling period. Plant sample collections occurred 4 times over 24 hours for all plant species at both study sites. When possible, identical sets of plant species were collected at both study sites; however, this was not possible during every season due to differences between the

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[15] Ruyle, G.B., editor. 1990. Some methods for monitoring rangelands and other natural area vegetation. College Agriculture Extension Report 9043, University of Arizona, Tucson, Arizona, USA.

2 sites. Samples (600 g fresh weight) were collected at dawn (±1 hour), midday (1300–1500), dusk (±1 hour), and midnight (1100–0100). Sampling over 24 hours was necessary for other research purposes and we combined these samples by species (4 per day) for all mineral analyses. To minimize damage to plants by harvesting, we collected <30% of the total biomass from individual plants (Wallmo and Regelin 1981, Roundy and Ruyle 1989). We collected leaves, stems, fruits, flowers, and new growth within 1.5 m of the ground to imitate the selection of plant parts by browsing pronghorn (AGFD[7] 1981). We weighed each plant sample in the field immediately after clipping, stored samples in paper bags, and froze them at –20°C within 24 hours after collection (Haufler and Servello[16] 1994, Higgins et al. 1994). We dried samples for 72–120 hours in an oven at 55°C and reweighed them (Higgins et al. 1994). We subtracted dry weights from field weights to obtain water content.

We ground dried plant material to a 2-mm particle size using a Model 4 Thomas-Wiley Laboratory Mill (A.H. Thomas Company[16], Philadelphia, Pennsylvania, USA). Daily samples were combined in this way because changes in mineral composition of plants over 24 hours were assumed to be minimal and not of interest for this study.

All mineral analyses were performed by the University of Arizona Veterinary Diagnostic Laboratory. Minerals quantified were copper, zinc, selenium, manganese, phosphorus, calcium, sulfur, molybdenum, sodium, potassium, and iron. All mineral analyses, except selenium, were conducted after acid digestion, using a mixture of 9 parts concentrated nitric acid and 1 part 70% perchloric acid. For each sample, 3 g of dried, ground plant material was heated and digested until clear using 25 ml of acid solution. The minerals were analyzed using the following techniques: atomic absorption for calcium, copper, iron, manganese, and zinc; atomic emission for potassium and sodium; colorimetric for molybdenum and phosphorus; and turbidimetric for sulfur. Selenium was determined by capillary gas chromatography with electron capture detection. All samples were diluted to fit standard curves for measurement.

We used Bartlett's test for homogeneity of variances and visual inspection of normal probability plots to examine original and transformed data sets for equal variance and for normality (Sokal and Rohlf 1995). We used Mann-Whitney U or Kruskal-Wallis tests (Sokal and Rohlf 1995) to compare means for plant mineral content because the assumptions for parametric tests were not met by data transformation. Data were pooled across sites, seasons, or sampling times for comparison and modeling when no significant differences existed.

We calculated forage consumption for 5 pronghorn diets using field data from 2 sites over 5 seasons, using a dry matter (DM) intake rate of 1.5 kg/animal/day. One diet was based on plant abundance measured during this study and assumed pronghorn use of forage plants in proportion to their availability (i.e., "no selection"). Two diets were based on forage selection described by AGFD[7] (1981) and the remaining 2 were based on Hughes[14] (1991) (i.e. "selection"). Two diets were

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[16] The use of trade names does not imply endorsement by the California Department of Fish and Game.

constructed for each of these previous studies to test minor differences in partitioning of diets and will not be discussed further in this paper.

We did not have data on seasonal intake rates for Sonoran pronghorn, which vary, so we used data from other studies. The dry matter intake rate of 1.5 kg/animal/day (Knox et al. 1969 [65 g/kg$^{0.75}$/day], Hobbs and Swift 1985, O'Gara and Yoakum 1992, Yoakum et al. 1996 [1-1.5 kg/44 kg animal/day]) was used to represent the daily food requirements of an adult male pronghorn (41–64 kg) (Yoakum 1978). We estimated mineral intake for each diet model by multiplying the dietary amount (ppm or percent composition) of each mineral by daily dry matter intake (g) for each vegetation species (Schwartz et al. 1977, Goodson et al. 1991). After calculating intake amounts for 11 minerals, we compared these values to published diet information for domestic sheep (NRC 1985, Puls 1994).

RESULTS

Vegetation Sampling

Estimates for total vegetation biomass (dry weight) on creosote flats at Agua Dulce were 659.7 kg/ha in February–March, 548.0 kg/ha in April–May, 418.8 kg/ha in June–July, 736.8 kg/ha in August–September, and 452.6 kg/ha in October–November. Estimates for washes at Agua Dulce for the same 5 seasons were 1,216.5, 1,058.8, 884.1, 1,228.5, and 979.5 kg/ha. Estimates for total vegetation biomass (dry weight) on creosote flats at Charlie Bell were 541.4 kg/ha in February–March, 496.5 kg/ha in April–May, 462.9 kg/ha in June–July, 497.7 kg/ha in August–September, and 563.5 kg/ha in October–November. Estimates for washes at Charlie Bell for the same 5 seasons were 834.2, 684.8, 718.6, 793.0, and 929.3 kg/ha.

Vegetation abundance at 2 study sites across 5 seasons varied widely, from 0 to approximately 250 kg/ha for individual species (Fox[17] 1997). The mean weights for harvested plots ranked 1 through 5 (Fox[17] 1997) met the assumption of linearity required for the use of the comparative yield method (Haydock and Shaw 1975).

Plant Mineral Content

Overall, few of the 11 minerals measured in forage and non-forage plants varied by season or site. Seasonal variation was low for all plant species combined and for forage species examined separately. Only potassium (P <0.001), phosphorus (P <0.001), and molybdenum (P = 0.003) differed significantly among the 5 seasons (all plant species and forage species only) (Kruskal-Wallis test).

For all plant species examined collectively, potassium content was highest in October–November (13,504.1±783.1 ppm), and lowest in June–July (6,237.5± 280.4 ppm). Phosphorus content was highest in April–May (3,541.8±158.1 ppm) and lowest in October–November (1,005.1±49.8 ppm); molybdenum content was highest in February–March (0.74±0.1 ppm) and lowest in June–July (0.40±0.1 ppm). For

[17] Fox, L.M. 1997. Nutritional content of forage in Sonoran pronghorn habitat, Arizona. M.S. Thesis, University of Arizona, Tucson, Arizona, USA.

forage species, the seasons with the highest and lowest values for potassium, phosphorus, and molybdenum were identical to those for all plant species combined (listed above). The minima and maxima were: potassium, October–November 13,747.1±960.9 ppm, June–July 6,099.3±293.3 ppm; phosphorus, April–May 3,614.4±190.6 ppm, October–November 996.1±60.9 ppm; molybdenum, February–March 0.81±0.1 ppm, June–July 0.45±0.1 ppm.

Potassium, phosphorus, molybdenum, and selenium differed significantly between the 2 study sites in 1 of 5 seasons each (Mann-Whitney U-tests, $P < 0.05$). Mean levels of copper ($P = 0.017$), manganese ($P = 0.006$), and iron ($P = 0.002$) differed between the Agua Dulce and Charlie Bell study sites for the 5 seasons combined. Due to these small differences, seasonal data are reported by site (Table 1), but were combined for further analyses. Mineral content of forage and non-forage species was not significantly different (Mann-Whitney U-tests) (Table 2).

Mineral Diet Models

We assessed mineral intake for 5 diet models for 2 sites over 5 seasons (50 models) (Fox[18] 1997). However, we report only the results of the "no selection" diet and 1 "selection" diet (Hughes[14] 1991) because these produced the minimum and maximum estimates. Mean values for mineral intake (Table 3) were obtained by calculation of the mineral intake for 5 seasons and 2 sites (n = 10) and mean intake values are presented due to lack of significant differences in prior analyses.

Estimates of mineral intake were different for the "no selection" and "selection" diets (Table 3). For the "no selection" diet, 6 of the 11 minerals (copper, zinc, selenium, manganese, phosphorus, and sodium) examined were marginal or deficient according to 1 or more published values for domestic sheep (Table 3). For the "selection" diet, copper, zinc, selenium, phosphorus, and sodium were low relative to at least one published requirement for domestic sheep (Table 3). Only manganese changed status when forage selection was incorporated into the model, increasing from 33.82 ppm (low) to 42.53 ppm (adequate) (Puls 1994).

DISCUSSION

Selection in domestic animals for growth, energy efficiency, and protein use and the widespread supplementation with minerals may inadvertently select for animals that absorb, use, and conserve minerals poorly (Robbins 1993). In this study we compare mineral intake by Sonoran pronghorn with the requirements of domestic sheep as a useful starting point to better understand the adequacy of pronghorn diets. During this study, we assessed quantities of 11 minerals present in plants within Sonoran pronghorn range on the CPNWR. We detected few significant differences in mineral content of plant species by site, season, or between forage and non-forage species. The "selection" diet models we constructed predicted pronghorn consumption of sodium, phosphorus, copper, zinc, and selenium to be inadequate to meet their physiological needs based on mineral requirements of domestic sheep. The presence of these minerals in forage plants in adequate amounts

Table 1. Mean mineral content (± standard error) for vegetation species sampled at 2 study sites for 5 seasons, from June 1995 to May 1996, on Cabeza Prieta National Wildlife Refuge, Arizona. Means for each mineral vary in significant digits reported. Values for all minerals are reported in parts per million (ppm), except calcium and sulfur, which are reported as percent dry matter (% DM).

Agua Dulce	Feb–Mar	Apr–May	Jun–Jul	Aug–Sep	Oct–Nov
Mineral	Mean SE	Mean SE	Mean SE	Mean SE	Mean SE
Copper	6.73±0.6	5.73±0.5	6.87±0.9	5.58±0.4	8.53±1.0
Zinc	15.34±1.9	18.08±3.0	13.72±1.7	13.29±1.1	21.15±2.3
Selenium	0.30±0.10	0.23±0.03	0.22±0.03	0.22±0.03	0.31±0.05
Manganese	54.61±11.7	37.40±6.0	44.05±9.8	52.04±15.6	54.28±9.9
Phosphorus	2,064.6±47	3,623.6±266	1,142.2±241	2,946.6±106	1,099.9±74.6
Calcium (% DM)	2.35±0.4	1.70±0.4	1.77±0.3	1.46±0.2	2.13±0.4
Sulfur (% DM)	0.16±0.02	0.13±0.02	0.15±0.02	0.11±0.01	0.17±0.03
Molybdenum	0.63±0.09	0.49±0.09	0.28±0.05	0.51±0.06	0.63±0.14
Sodium	536.4±244	577.7±243	608.0±139	646.4±300	487.8±234
Potassium	7,624.2±388	6,912.7±396	6,189.6±387	7,595.2±232	15,660.8±1023
Iron	87.18±8.9	98.28±12.6	—	263.77±191.6	93.03±7.7
Charlie Bell					
Copper	5.41±0.6	5.37±0.5	6.09±0.6	5.53 ±0.4	5.35±0.6
Zinc	15.52± 2.2	16.08±3.3	19.77±5.1	18.60 ±3.0	16.62±2.2
Selenium	0.26±0.04	0.30±0.04	0.28±0.06	0.28 ±0.02	0.27±0.04
Manganese	29.01±3.0	26.70±4.2	45.97±8.5	39.46 ±12.1	27.59±3.6
Phosphorus	1,855.6±50	3,441.7±146	923.0±60	2,567.7±209	891.2±44
Calcium (% DM)	1.77±0.32	1.45±0.30	1.65±0.17	1.32±0.2	1.52±0.2
Sulfur (% DM)	0.15±0.02	0.14±0.02	0.18±0.02	0.13±0.02	0.12±0.02
Molybdenum	0.90±0.22	0.55±0.07	0.55±0.10	0.76±0.09	0.32±0.06
Sodium	809.9±369	1,015.5±510	503.6±83	511.5±245	760.8±376
Potassium	8,258.9±434	6,208.9±183	6,290.7±432	8,858.2±583	10,916.0±498
Iron	126.76±11.7	124.11±9.4	—	115.53±12.6	100.27±14.9

Table 2. Mean mineral content ± SE and sample sizes for forage and non-forage species sampled at 2 locations on Cabeza Prieta National Wildlife Refuge, Arizona, from June 1995 to May 1996. Mean values vary in significant digits reported and are in parts per million, with the exception of calcium and sulfur, which are reported as percent dry matter (% DM). Means across rows (forage vs. non-forage) are not significantly different at $P < 0.05$ (Mann-Whitney U-tests).

	Forage[a]		Non-forage[b]	
Mineral	Mean SE	n	Mean SE	n
Copper	5.95±0.2	78	6.91±0.5	25
Zinc	17.55±1.0	78	14.41±1.2	25
Selenium	0.26±0.01	78	0.29±0.02	25
Manganese	36.39±2.1	78	59.64±10.8	25
Phosphorus	2,105.41±128.3	78	1,935.84±193.5	25
Calcium (% DM)	1.83±0.1	78	1.43±0.1	25
Sulfur (% DM)	0.15±0.01	78	0.14±0.01	25
Molybdenum	0.57±0.04	78	0.50±0.1	25
Sodium	700.27±108.9	78	441.27±135.9	25
Potassium	8,580.63±400.0	78	8,596.76±543.5	25
Iron	132.35±35.2	65	108.02±10.9	20

[a] *Ambrosia dumosa, Beloperone californica, Encelia farinosa, Euphorbia* spp., *Hyptis emoryi, Janusia gracilis, Krameria* spp., *Olneya tesota, Opuntia fulgida, Prosopis juliflora,* and *Sphaeralcea* spp.

[b] *Ambrosia deltoidea, Jatropha cuneata, Larrea tridentata,* and *Sapium biloculare.*

is essential to the maintenance of healthy pronghorn individuals and, consequently, populations (Arthur and Gates 1988, Puls 1994, Ammerman et al. 1995). Lack of essential dietary minerals may impair population health and potentially reduce productivity.

Sodium serves many functions in the ruminant animal (NRC 1985). It maintains osmotic pressure, regulates the acid-base balance, and controls water metabolism in tissues. Minimum salt intake is probably >0.9 g/day (0.06% of diet). Sheep consume 15–30 g of salt per day when offered ad libitum. Dietary sodium estimated from the forage selection diet models for this study was 442 (± 82) ppm (0.044% dietary DM), which is below the minimum requirement for sheep (Table 3).

Phosphorus, along with calcium, is important in the growth and development of the skeletal system (NRC 1985). The dietary requirement for phosphorous is 0.16–0.38% DM (NRC 1985), or 0.25–0.50% (Puls 1994). Dietary phosphorous estimated from diet models for this study was 2,294 (± 333) ppm (0.23% dietary DM), which is below the requirement for 1 of 2 published values for sheep (Puls 1994) (Table 3).

Copper deficiency causes ataxia or "swayback" in domestic lambs. Signs include muscular incoordination, partial paralysis of hindquarters, and degeneration of nerve fiber sheaths. Sulfur and molybdenum form insoluble complexes with copper, reduce its absorption, and increase the dietary requirements. Dietary copper estimated

Table 3. Mineral intake for 2 diet models (dry matter intake of 1.5 kg/animal/day) as estimated from vegetation sampled from June 1995 to May 1996 on Cabeza Prieta National Wildlife Refuge, Arizona. All minerals reported as mg/kg dietary dry matter, except calcium and sulfur which are reported as percent dietary dry matter (%DM). These are for 10 models, except iron where only 8 models where available (see text).

Mineral	Mean ± SE	NRC (1985)[a]	Puls (1994)[b]
No Forage Selection[c]			
Copper	6.23±0.54	Low	Adequate
Zinc	22.51±1.73	Adequate	Low
Selenium	0.29±0.02	High	Low
Manganese	33.82±2.86	Adequate	Low
Phosphorus	2,136.31±347.68	Adequate	Low
Calcium (%DM)	1.86±0.11	High	High
Sulfur (%DM)	0.17±0.01	Adequate	Adequate
Molybdenum	0.67±0.10	Adequate	Adequate
Sodium	547.38±93.08	Low	Low
Potassium	8,436.24±862.88	High	Adequate
Iron	104.28±4.63	High	Adequate
Forage Selection[d]			
Copper	5.14±0.25	Low	Adequate
Zinc	17.52±2.03	Low	Low
Selenium	0.24±0.02	High	Low
Manganese	42.53±5.49	High	Adequate
Phosphorus	2,294.09±332.65	Adequate	Low
Calcium (% DM)	2.34±0.27	High	High
Sulfur (% DM)	0.14±0.01	Adequate	Adequate
Molybdenum	0.57±0.09	Adequate	Adequate
Sodium	441.45±81.46	Low	Low
Potassium	8,463.42±1,159.59	High	Adequate
Iron	179.40±87.93	High	Adequate

[a] Model values compared to NRC (1985).
[b] Model values compared to Puls (1994).
[c] No selection diet models; forage used in proportion to availability.
[d] Selection diet models based on Hughes[14] (1991).

from diet models for this study was below the requirement for domestic sheep according to the National Research Council (1985) (Table 3).

Zinc deficiencies result in a decrease in appetite and reduction in growth rate. Other symptoms in domestic sheep include excess salivation, parakeratosis, wool loss, reduced testicular development, or reproductive problems. Diets high in calcium can adversely affect zinc use (NRC 1985). Dietary zinc estimated from diet models in this study was generally below published rquirements for domestic sheep (Table 3).

Selenium deficiency results in cardiac and skeletal muscle degeneration (white muscle disease). Southwestern Arizona is within the geographic range for adequate selenium presence and most domestic forages and grains contain adequate selenium (NRC 1985). Although domestic grains contain adequate selenium for most

livestock, wild populations of plants used by pronghorn may not contain adequate amounts. Dietary selenium estimated from diet models in this study was below 1 of the 2 published requirements for domestic sheep (Puls 1994).

In black-tailed deer, *Odocoileus hemionus columbianus*, selenium plays a role in reproductive success. When their diet was supplemented with selenium, fawn survival increased from 0.32 fawns/female to 0.82 fawns/female (Flueck 1994).

Construction of diets is difficult due to complicated forage selection by herbivores. Herbivores attempt to select a diet that meets minimum nutritional requirements and is below the maximum allowable amounts of secondary and/or toxic compounds (Hanley 1982). During this study, no secondary compounds or toxic substances were measured. Sonoran pronghorn may not use certain plant species because of secondary compounds, toxic substances, habitat microsite differences, or more general dietary constraints. Some or all of these factors may act to prevent pronghorn from using a combination of plants that could provide them with adequate minerals.

While constructing diet models for each site, season, and selection type, we encountered 2 inadequacies. The first was the lack of year-round data for plant species present in Sonoran pronghorn diet. Only 2 studies (AGFD[7] 1981, Hughes[14] 1991) provided quantitative diet information for Sonoran pronghorn, and these did not contain diet information for the entire year. Other studies (Carr[12, 10] 1970, 1972) listed plants considered to be forage for Sonoran pronghorn but lacked proportional data.

The 2nd inadequacy was the lack of forbs during our study. In the past, rainfall to allow forbs to grow during summer monsoons occurred on our study sites (T.L. Cutler, University of Arizona, personal communication); however, few forbs grew on these sites during June 1995–May 1996. Pronghorn make heavy use of forbs as they become seasonally available (Beale and Smith 1970) and forbs are a preferred food in all seasons (Yoakum 1990). Forbs constitute anywhere from <20 to 99% of pronghorn diet (Buechner 1950, Beale and Smith 1970, Mitchell and Smoliak 1971, Stephenson et al. 1985, Hughes[14] 1991) depending on rainfall or other factors that influence annual vegetation. Pronghorn can consume a wide variety of forbs, but as few as 5 species can make up 90% of the total diet in certain seasons. Forbs are a high quality food and an important dietary item that we could not consider during this study. Thus, this analysis is probably a "worst case" scenario, especially considering that we used domestic sheep requirements.

Conservation of healthy wildlife populations depends largely on adequate habitat, on our ability to assess habitat quality, and on our understanding of the physiological needs of animals (Morrison et al. 1992, Litvaitis et al. 1994). The importance of knowledge about forage quality and availability for ruminant herbivores has been well documented (e.g., Robbins 1993, Van Soest 1994, Cook et al. 1996) and mineral requirements are an important component of ruminant nutrition (Robbins 1993, Puls 1994, Van Soest 1994, Ammerman et al. 1995).

Forage quality information and availability data such as we present here can be used to estimate habitat quality for Sonoran pronghorn, identify potential population limiting factors, and aid in revising and improving recovery strategies. By

summarizing current diet information available for Sonoran pronghorn, collecting additional field data on forage species, and using models such as we present here, wildlife managers can identify specific targets for management actions and concentrate expensive recovery efforts for maximum benefit to pronghorn populations.

Models constructed during this study indicated that diets of pronghorn on the CPNWR, at least in years of poor forb production, may be deficient in sodium, phosphorus, copper, zinc, and selenium. Although limitations to our field data and models exist, we recommend that wildlife managers treat mineral deficiencies in Sonoran pronghorn diet as a possible hindrance to the health and growth of the population.

Future research should focus on collecting comprehensive data about pronghorn habitat use, attributes of forage species, pronghorn nutritional and mineral requirements, and current mineral deficiencies. Laboratory examination of appropriate tissues should be carried out to determine if Sonoran pronghorn exhibit signs or symptoms of deficiencies in essential minerals.

Wildlife managers should carefully evaluate the ability of Sonoran Desert vegetation associations to support viable Sonoran pronghorn populations. This should occur prior to more costly and difficult actions, such as adding water to desert habitat, translocating animals, or habitat manipulation. This type of detailed, quantifiable habitat information is an essential part of understanding the relationship between pronghorn and their habitat. This type of habitat evaluation is labor intensive and area specific, but will yield important information about factors limiting the population (Leopold 1933, Robbins 1993). If mineral availability or other variables associated with forage quality limit Sonoran pronghorn, other management actions directed at pronghorn recovery may have little or no beneficial effect.

ACKNOWLEDGMENTS

This research was funded by the Office of Naval Research (Grant No. N00014-94-10910) and the University of Arizona. We thank A. Averill, P. Cutler, D. Griffith, M. Grinder, A. McLuckie, R. Carmichael, C. Murray, and D. Zaiti for field assistance; D. Perry-Detzer for laboratory work; V. Catt and T. Haag for administrative assistance; and the staff of CPNWR.

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Received: 15 March 2000
Accepted: 4 August 2000

California Fish and Game 86(3):175-185 2000

DESCRIPTION OF LABORATORY-REARED LARVAE OF CALIFORNIA GRUNION AND COMPARISONS WITH LARVAE OF TOPSMELT AND JACKSMELT

LOURDES VÁSQUEZ-YEOMANS and MARTHA VALDÉZ-MORENO
Laboratorio de Plancton
Departamento de Ecología y Sistemática Acuática
El Colegio de la Frontera Sur
A.P. 424, C.P. 77000
Chetumal, Quintana Roo, México
e-mail: lvasquez@ecosur-qroo.mx

WILLIAM J. RICHARDS
Southeast Fisheries Science Center
75 Virginia Beach Drive
Miami, Florida 33149

Larval development of the California grunion, *Leuresthes tenuis*, from hatching to 60-days old (7.4–17.2 mm) is described based on laboratory-reared larvae. The description includes changes in pigmentation patterns and the developmental sequence of fins. The California grunion showed distinctive larval pigmentation patterns on the head, dorsal and ventral margins, and lateral midline of the tail. We compared our description with others of the same species and found differences (pigment over the forebrain and unpigmented lateral midline in the yolk-sac stage, and pigment on upper jaws in the postflexion stage) that should be corroborated in future research. We found a strong morphological similarity between field-collected and laboratory-reared larvae. In order to identify atherinid larvae co-ocurring in the same area, we compared the pigmentation patterns with those of topsmelt, *Atherinops affinis*, and jacksmelt, *A. californiensis*. California grunion and jacksmelt larvae show similar patterns and differ from topsmelt.

INTRODUCTION

The Baja California Peninsula has an ecologically interesting fish fauna (Arriaga-Cabrera et al. 1998). One common fish endemic to this area is the California grunion, *Leuresthes tenuis*. It is distributed along the open coast and in bays from San Francisco, California to Bahia Magdalena, Baja California Sur (Moffatt and Thomson 1975) and schools near shore, usually close to the surface. It spawns on beaches with a semilunar periodicity from February through August, peaking in April and May. Eggs incubate in the sand for about 2 weeks and hatch when the next series of high spring tides stir the sand (Thompson 1919, Walker[1] 1949). At

[1] Walker, B.W. 1949. The periodicity of spawning by the grunion *Leuresthes tenuis*, an atherine fish. Ph.D. Dissertation, Scripps Institution of Oceanography, San Diego, California, USA.

hatching, larvae are large (6.7–8.9 mm), well developed, and very active (David 1939, Hubbs 1965, May 1971).

The California grunion and 2 other species of atherinids, topsmelt, *Atherinops affinis*, and jacksmelt, *A. californiensis*, share the same geographic range and their reproductive seasons overlap. Topsmelt and California grunion have the same reproductive season (March–August), and the April–July spawning peak for topsmelt encompasses that of California grunion. In contrast, the jacksmelt spawns from October to April and its larvae occur predominantly in March and April, when larvae of all 3 of these morphologically similar species may co-occur.

Although there is information about the use of California grunion eggs and larvae for experiments designed to determine factors affecting embryonic and larval growth and survival (e.g., Vásquez-Yeomans and Sosa-Cordero 1992, Rosales-Casián 1994, Darken et al. 1998), descriptions of larval development are few. David (1939) reared eggs of this species in the laboratory but described only its embryonic development and 1 larval stage. Wang[2] (1981) described some morphological characteristics of prolarvae, postlarvae, and juvenile stages of the California grunion. Watson (1996) showed only 3 drawings of California grunion early stages (newly hatched, flexion, and transformation).

We present a sequential, detailed description of the larval development of California grunion from hatching through 60 days after hatching (dah) in order to complete the previous descriptions and to aid larval identification in field collections where California grunion larvae may be confused with topsmelt and jacksmelt larvae. The larval description refers mainly to pigmentation patterns and the sequential development of fins.

METHODS

Several adult California grunions were collected on 26 April 1986 at Playitas Beach, Ensenada, Baja California, Mexico. Eggs from 6 females were fertilized with sperm of 3 males and incubated. Following fertilization, eggs were maintained in suspension in glass bottles containing 350 ml of filtered seawater at 17.8°C. After 10 days, hatching was stimulated with a slight but sudden increase in aeration. Hatched larvae were then cultured in 20-liter rectangular glass tanks with filtered seawater at 18.3 ± 0.5°C and a salinity of 32.9 ± 1‰. Larvae were fed with *Tetraselmis suecica* and brine shrimp, *Artemia* sp., nauplii (Vásquez-Yeomans and Sosa-Cordero 1992).

Live larvae were randomly selected and anesthetized with MS222. Body length, equivalent to notochord length (distance from the tip of the snout to the tip of the notochord) in preflexion and flexion stage larvae and equivalent to standard length (distance from the tip of the snout to the posterior margin of the hypural plate) in postflexion, juvenile, and adult stages (Moser 1996), was measured to the nearest 0.1 mm. Larvae were preserved in 10% formalin.

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[2] Wang, J.C.S. 1981. Taxonomy of the early life stages of fishes: Fishes of the Sacramento-San Joaquin Estuary and Moss Landing Harbor-Elkhorn Slough, California. Ecological Analysts, Inc., Concord, California, USA.

Developmental stages were grouped following Kendall et al. (1984): yolk-sac stage (Ys), 0 dah; preflexion stage (Prfs), 4–10 dah; flexion stage (Fs), 13–22 dah; postflexion stage (Pofs), 25–40 dah; and transformation stage (Ts), 45–60 dah. We selected 8 larvae of each stage for description. Drawings were made using a camera lucida.

RESULTS

Yolk-sac Stage

Yolk-sac-stage larvae were 7.1–7.6 mm long. These larvae had 5 melanophores on the head: 3 large ones over the midbrain, 1 on the hindbrain, and 1 small one on the forebrain (Fig. 1A). This pigmentation pattern on the head was designated as PH. Larvae had a series of 12–20 large melanophores along the dorsal margin of the body. The lateral midline of the tail was unpigmented on most larvae and the ventral margin was unpigmented in all. Two melanophores were present dorsally on the gut, but none laterally or ventrally (Table 1).

Preflexion Stage

Preflexion larvae measured 7.9–9.8 mm in length. In addition to the PH pattern, 2 variations on the head pigmentation were present in 9% of the larvae: 1) 4 melanophores, 3 large ones over the midbrain and 1 over the hindbrain, and 2) 6 melanophores, 4 over the midbrain, 1 over the hindbrain, and a small one over the forebrain. A small melanophore was present on each nostril. The number of large melanophores on the dorsal margin of the trunk and tail increased slightly from 12–20 to 13–22 and 10–19 melanophores formed along the lateral midline of the tail. Four or 5 large melanophores occurred dorsally on the gut, but its lateral and ventral surfaces remained unpigmented (Table 1).

Yolk-sac absorption was completed in the youngest preflexion larvae collected (4 dah). Development of the caudal fin started 10 dah (9.8 mm) when the 1st rays appeared (Fig. 1B).

Flexion Stage

The length range of flexion stage (Fs) larvae was 10.2–11.9 mm. Head pigmentation was predominantly of the PH pattern (Fig. 1C). In addition, 1 small melanophore was located under the preopercle. There were 18–25 large melanophores along the dorsal margin of the body. Several larvae showed a continuous pigmented stripe along the lateral midline of the tail. Dorsal pigmentation on the gut (5–7 melanophores) was stronger. Four or 5 small melanophores occurred on the base of the anal fin (Table 1), which had not yet formed (Fig. 1C).

Notochord flexion started 13 dah at 10.2 mm (Fig. 1C) and was complete 22 dah at 11.9 mm. The 1st anal fin rays appeared 19 dah (11.0 mm) and the 1st rays of the 2nd dorsal fin appeared at 22 dah (11.9 mm). The number of caudal fin rays increased from 8 to 10 at 10.2 mm (Fig. 1C).

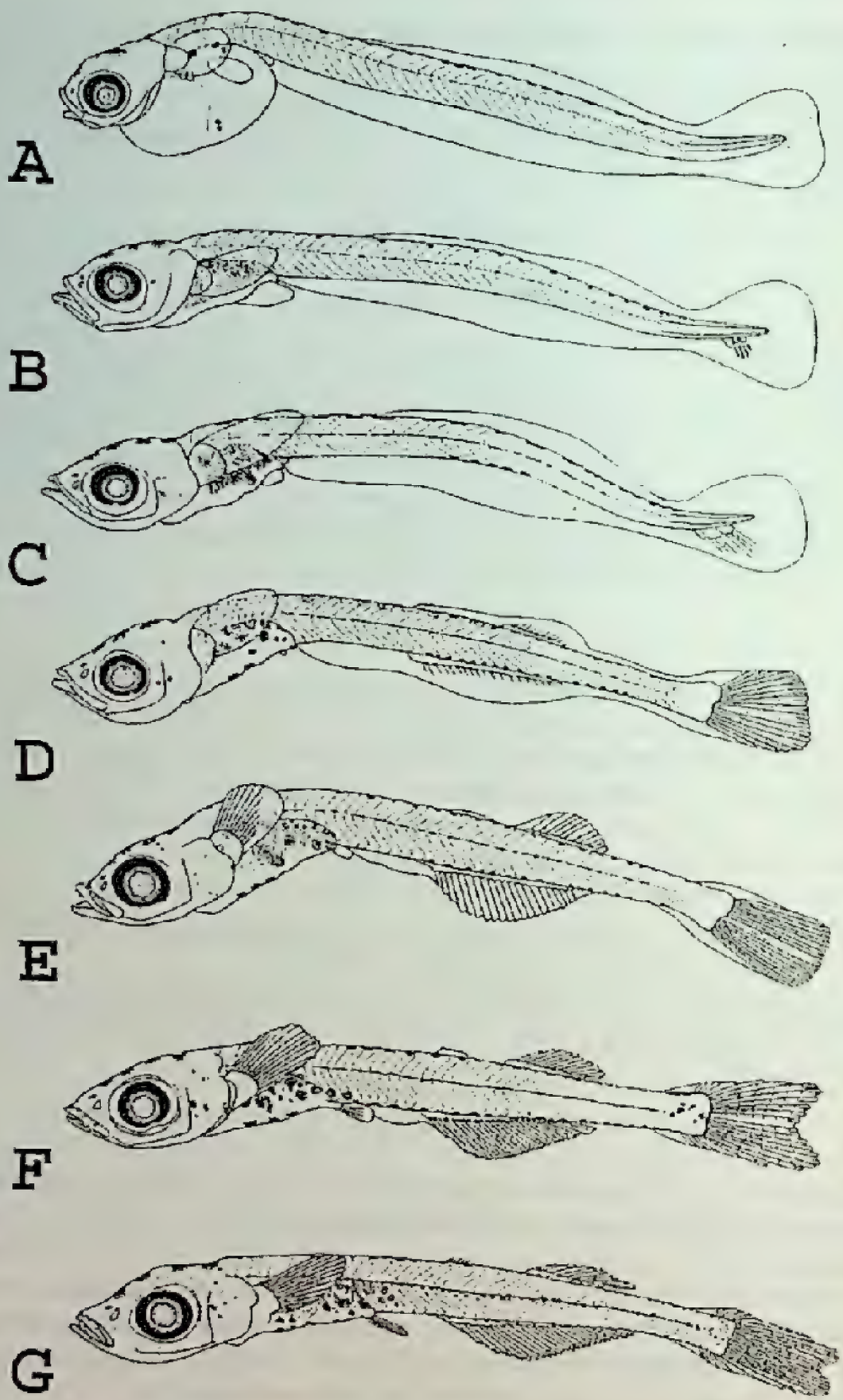

Figure 1. Larval stages of California grunion in lateral view: A) yolk-sac stage, 7.1–7.6 mm; B) preflexion stage, 7.9–9.8 mm; C) flexion stage, 10.2–11.9 mm; D) postflexion stage, 12.2–15.0 mm; E) postflexion stage, 14mm; F) transformation stage, 15.4–16.1 mm; G) transformation stage, 17.2 mm.

Table 1. Pigmentation patterns for topsmelt, jacksmelt, and California grunion larvae. Mps = melanophores, 2D = second dorsal fin, P_1 = pectoral fin, P_2 = pelvic fin, PH = pigmentation pattern on head, nr = not reported, and Pofs = postflexion stage.

	Topsmelt[a]	Jacksmelt[a]	California grunion[a]	California grunion[b]
Yolk-sac				
Head	3 large mps over midbrain, 1 over hindbrain	3 large mp's over midbrain and 1 over hindbrain	3 large mp's over midbrain and 1 over hindbrain	3 large mp's over midbrain, 1 on hindbrain, a small one on forebrain
Dorsal	16–19 mp's on dorsal margin to last myomere	17–21 mp's on dorsal margin to 2nd–6th myomere	14–20 large mp's on dorsal margin to the last myomere	12–20 large mp's on dorsal margin, reaching 2nd or 3rd myomere from the last
Lateral	4–17 mp's on lateral midline of tail	0–7 mp's on lateral midline of tail	3–13 mp's on midline of tail	unpigmented lateral midline
Gut	mps dorsally and ventrally on gut	mps dorsally on gut	mps dorsally on gut	2 mps dorsally on gut
Ventral	nr	nr	nr	none
Preflexion				
Head	nr	nr	1 mp added over forebrain, at each nostril, under preopercle, and in otic capsule	usually similar to yolk-sac stage PH, plus 1 mp at each nostril
Dorsal	nr	nr	nr	13–22 mp's on dorsal margin

Table 1. (continued)

	Topsmelt[a]	Jacksmelt[a]	California grunion[a]	California grunion[b]
Lateral	nr	nr	nr	10–19 mp's along lateral midline of tail
Ventral	series of mps along ventral margin of tail	nr	nr	none
Vertebral	nr	nr	nr	none
Gut	nr	nr	nr	4–5 mp's dorsally
Flexion				
Head	2 mps over forebrain and 1 at each nostril, under hindbrain, on jaws, and gill cover; mps increase on head	1 mp over forebrain and 1 at each nostril	nr	PH pattern plus 1 small mp under preopercle
Dorsal	nr	nr	18–27 mp's on dorsal margin	18–25 mp's on dorsal margin
Lateral	pigment increases on lateral midline; extends from myomere 4–5 to end of tail	pigment increases along lateral midline, reaches trunk by end of Fss	nr	pigment becomes a continuous stripe
Ventral	nr	mps on ventral margin; begins during Fs	mps on ventral margin; begins in Fs	4–5 small mps on anal fin

Table 1. (continued)

	Topsmelt[a]	Jacksmelt[a]	California grunion[a]	California grunion[b]
Vertebral	mps on hypural margin	nr	internal mps under vertebral column	none
Gut	nr	nr	nr	5–7 mp's dorsally
Postflexion				
Head	nr	mps on gill cover; mps increase on head	mps increase on head	mps increase on head, small mps on upper jaw
Dorsal	mps increase on dorsum, forming on 2D bases and spreading onto some rays	mps gradually increase primarily in latter part of Pofs; mps may form on some 2D bases late in Pofs	nr	25–33 mp's on dorsal margin
Lateral	nr	nr	10–20 mps on lateral midline, extend to P_1 bases	mp's increase to 28–35
Ventral	nr	nr	mps extend forward as double row and reach P_2 bases	mps increase on anal fin base, extend forward as double row
Vertebral	mps on caudal rays and an internal series above and below vertebral column	internal mps under vertebral column, over last few vertebrate and on hypural margin	nr	none

Table 1. (continued)

	Topsmelt[a]	Jacksmelt[a]	California grunion[a]	California grunion[b]
Gut	pigment spreads ventrad on gut	pigment spreads ventrad on gut	pigment spreads ventrad to surround gut	pigment spreads ventrad on gut
Transformation				
Head	pigment increases on head	nr	nr	pigment stronger on the anterior part of head and both jaws
Dorsal	pigment increases dorsolaterally on trunk, tail, and on 2D	pigment increases dorsally	pigment heavy on dorsum	pigment increases on the dorsal margin (26–38 mp's)
Lateral	lateral stripe broadens on tail	lateral stripe broadens on tail	broad lateral stripe	broad lateral stripe
Ventral	pigment increases on anal and caudal fins	ventral margin series reaches P_2 base, a few mps on caudal fin	double row of mps on ventrum, heavy pigment on caudal rays	mps increase on anal fin base (22–26 mp's), caudal peduncle, and on caudal rays
Vertebral	nr	nr	nr	nr
Gut	mps increase on gut	nr	nr	pigmentation becomes stronger on gut

[a] Watson(1996)
[b] This study

Postflexion Stage

Postflexion stage larvae ranged from 12.2–15.0 mm in length. Pigmentation on the head, along the dorsal margin (25–33 melanophores), and along the lateral midline (28–35 melanophores) was stronger than in previous stages (Fig. 1D). A few larvae at 40 dah (15.0 mm) had small pigment spots on upper jaw and some pigmentation on the ventral side of the gut, but all larvae showed increased pigmentation on the anal fin base. This extended forward as a double row and reached the pelvic fin bases (Table 1).

Larvae 25 dah (12.2 mm) had 7–12 anal fin rays and 5–7 rays on the 2nd dorsal fin (Fig. 1D). The first pectoral fin rays (4–6) were visible 28 dah (12.9 mm). At 34 dah (14.0 mm) larvae had 10 rays on the 2nd dorsal fin, 22 rays on the anal fin, and a fin-fold on the 1st dorsal fin appeared (Fig. 1E). The pelvic fins appeared at 40 dah (15.0 mm).

Transformation Stage

Lengths of transforming specimens ranged from 15.4–17.2 mm. Pigmentation was stronger on the anterior part of the head, both jaws, the dorsal margin (26–38 melanophores), the lateral midline, the dorsal and ventral surfaces of the gut, and the anal-fin base (22–26 melanophores) (Table 1). Melanophores appeared on the caudal peduncle and on several caudal rays at this stage and increased later in the stage at 16.1 mm (Fig. 1F). The 1st pelvic fin rays (3–4) were visible at 16.1 mm. The 1st rays on the 1st dorsal fin appeared and pectoral fin and pelvic fin development was complete at 60 dah (17.2 mm) (Fig. 1G). Only 2 transformation-stage larvae had developed scales (60 dah, 17.2 mm).

DISCUSSION

In general, descriptions of larval development of laboratory-reared California grunion (David 1939, present study) are similar to those reported from field material (Wang[2] 1981, Watson 1996). However, our description of the pigmentation of California grunion larvae differs somewhat from that of Watson (1996) in 3 ways. 1) Our yolk-sac larvae had a small pigment spot over the forebrain similar to David's (1939) description, but not reported by Watson. 2) Our yolk-sac larvae showed no pigmentation on the lateral midline of the tail. Wang's[2] (1981) newly hatched larvae also lacked lateral pigment, whereas Watson found 3–13 melanophores (Table 1). 3) Our larvae underwent notochord flexion later (13 dah vs Watson's ca. 11 dah) and at a larger size (10.2–11.9 mm vs 8.9–9.6 mm).

Length and number of myomeres can be useful larval identification characters. Lengths of our newly hatched California grunion larvae (7.1–7.6 mm) approximate those reported by David (1939) (6.5–6.75 mm), Watson (1996) (6.5–7.5 mm), and Darken et al. (1998) (6.93 mm), but differ greatly from the length reported by Wang[2] (1981) (4.6 mm). Nevertheless, the hatching length can be useful in distinguishing topsmelt, jacksmelt, and California grunion. Topsmelt larvae hatch at a smaller

length (4.3–5.4 mm), compared with jacksmelt (6.0–9.0 mm), and California grunion (6.5–7.6 mm) (Middaugh et al. 1990, Watson 1996, this study). Thus, post-hatch California grunion larvae are easily distinguished from topsmelt by size. Jacksmelt larvae can be separated from the others by the number of myomeres, 50–54 (usually 51–53) vs 47–50 myomeres in California grunion and 44–52 (usually 47–48) for topsmelt.

Pigmentation differences also help distinguish the topsmelt from the other 2 species. The most obvious difference is that the topsmelt has melanophores on both dorsal and ventral margins of the gut in the yolk-sac stage. The last myomere also has pigmentation on the dorsal surface. In the flexion stage, the topsmelt is unique because it has 2 melanophores over the forebrain. In the postflexion stage, the topsmelt was characterized by pigmentation above and below the vertebral column and on the 2nd dorsal fin bases with melanophores spreading onto some rays, whereas the California grunion was separated by the pigmentation on its ventral margin which extends forward as a double row, reaching the pelvic fin bases. Pigment was present on the upper jaw of California grunion but not on the other 2 species.

For older larvae (transformation stage), these 3 species are more difficult to separate. The topsmelt is most easily recognized because the other 2 overlap in several characters. At the transformation size, other characteristics such as morphometrics, meristics, and osteology should be considered because pigmentation patterns are insufficient to differentiate the 3 species.

ACKNOWLEDGMENTS

We thank the Centro de Investigación Científica y de Educación Superior de Ensenada, especially the personnel of the Laboratorio de Ecología Pesquera, for providing facilities to carry out the experimental cultures. We also thank R. Vásquez-Yeomans for her participation in the laboratory work. M. Elías-Gutiérrez, E. Suárez-Morales, M. Schaadt and 1 anonymous reviewer made useful comments on this manuscript. This work was supported by the Mexican Consejo Nacional de Ciencia y Tecnología.

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Received: 2 February 2000
Accepted: 21 June 2000

California Fish and Game 86(3):186-207 2000

ANNOTATED LIST OF THE BIRDS OF CALIFORNIA

CALIFORNIA BIRD RECORDS COMMITTEE
c/o Western Foundation of Vertebrate Zoology
439 Calle San Pablo
Camarillo, California 93012-8506

This is the official list of California birds as recognized by the California Bird Records Committee (CBRC), sponsored by the Western Field Ornithologists (WFO). Updates to this list are available on the Internet at http://www.wfo-cbrc.org/cbrc/ca_list.html. Committee reports are published annually in the WFO journal, *Western Birds*. The taxonomy and sequence of this list follow the 7th edition of the *A.O.U Check-List of North American Birds* (American Ornithologists' Union, Washington, D.C., USA, 1998) and the 42nd Supplement to the check-list (*Auk* 117:847-858, July 2000). A total of 613 species is included on the main list, 8 of which are non-native species, and 2 of which have been extirpated within historical times. An additional 17 naturalized species not yet evaluated by the CBRC are also listed, along with 4 species that have been recorded in the State, but are of uncertain natural occurrence and therefore are included in a supplemental list. To be considered accepted on the main California list, at least 1 record of the species must be reviewed and accepted by the CBRC. Species in the main list lacking annotation (or marked with just an E or I) are supported by at least 1 extant specimen for which there is convincing evidence that it was obtained in California. Species marked with a non-specimen annotation are supported by at least 1 record for which there is at least 1 photograph (P), videotape (V), or tape recording of vocalization (T) that clearly demonstrates definitive characters and for which there is adequate supporting evidence that the photograph, video, or recording was made in California. Species marked with an S are supported only by sight records with 1 or more convincing written descriptions. Documentation supporting all records reviewed by the CBRC (except for the physical specimens in specimen-supported records) is permanently archived at the Western Foundation of Vertebrate Zoology and is available to researchers.

The CBRC solicits information on all occurrences in California of species on its Review List (those annotated below with an asterisk), as well as species unrecorded in California. In general, review species average 4 or fewer occurrences per year in California, and have been recorded fewer than 100 times. Documentation should be sent to Dr. Michael M. Rogers, CBRC Secretary, P.O. Box 340, Moffett Field, California 94035-0340 (or by e-mail at m.m.rogers@worldnet.att.net). Documentation concerning the potential establishment of exotic species not currently on the main list is also sought.

LEGEND

N Regular nesting species (289 native species, 8 non-native species, plus 17 recently naturalized species)
n Has nested at least once (not necessarily successfully), but not considered a regular nesting species (23 species)
n* Nesting activity has occurred (e.g., nest building), but not known to have reached the egg stage or involved either individual birds or members of hybrid pairs (12 species)
n^5 or N^5 Nesting strongly suspected but never confirmed (5 species)
( ) Indicates former nesting status (4 formerly nesting species)
* California Bird Records Committee Review Species (166 species)
I Introduced: non-native but now established in California (8 species)
E Extirpated from California (2 species)

For species not supported by specimens (81 species):

P At least 1 record supported by identifiable photograph (75 species)
V At least 1 record supported by identifiable videotape (12 species)
T At least 1 record supported by identifiable taped vocalization (6 species)
S Supported only by sight records (5 species)

Special status species:

SE State-listed as Endangered (18 species/subspecies)
ST State-listed as Threatened (6 species/subspecies)
FE Federally listed as Endangered (11 species/subspecies)
FT Federally listed as Threatened (7 species/subspecies)
FPT Federally proposed as Threatened (1 species)
FPD Federally proposed for Delisting (2 species/subspecies)

MAIN LIST

GAVIIFORMES - Loons

Gaviidae - Loons
red-throated loon, *Gavia stellata*
arctic loon, *Gavia arctica* - *PV
Pacific loon, *Gavia pacifica*
(n) common loon, *Gavia immer*
yellow-billed loon, *Gavia adamsii* - *

PODICIPEDIFORMES - Grebes

Podicipedidae - Grebes
n least grebe, *Tachybaptus dominicus* - *

N pied-billed grebe, *Podilymbus podiceps*
n* horned grebe, *Podiceps auritus*
red-necked grebe, *Podiceps grisegena*
N eared grebe, *Podiceps nigricollis*
N western grebe, *Aechmophorus occidentalis*
N Clark's grebe, *Aechmophorus clarkii*

PROCELLARIIFORMES - Tube-nosed Swimmers

Diomedeidae - Albatrosses
light-mantled albatross, *Phoebetria palpebrata* - *PV
wandering albatross, *Diomedea exulans* - *P
Laysan albatross, *Phoebastria immutabilis*
black-footed albatross, *Phoebastria nigripes*
short-tailed albatross, *Phoebastria albatrus* - *FE

Procellariidae - Shearwaters and Petrels
northern fulmar, *Fulmarus glacialis*
great-winged petrel, *Pterodroma macroptera* - *PV
Murphy's petrel, *Pterodroma ultima*
mottled petrel, *Pterodroma inexpectata* - *
dark-rumped petrel, *Pterodroma phaeopygia* - *P, FE[1]
Cook's petrel, *Pterodroma cookii*
Stejneger's petrel, *Pterodroma longirostris* - *P
Bulwer's petrel, *Bulweria bulwerii* - *P
streaked shearwater, *Calonectris leucomelas* - *
pink-footed shearwater, *Puffinus creatopus*
flesh-footed shearwater, *Puffinus carneipes*
greater shearwater, *Puffinus gravis* - *P
wedge-tailed shearwater, *Puffinus pacificus* - *P
Buller's shearwater, *Puffinus bulleri*
sooty shearwater, *Puffinus griseus*
short-tailed shearwater, *Puffinus tenuirostris*
Manx shearwater, *Puffinus puffinus* - *PV
black-vented shearwater, *Puffinus opisthomelas*

Hydrobatidae - Storm-Petrels
Wilson's storm-petrel, *Oceanites oceanicus*
N fork-tailed storm-petrel, *Oceanodroma furcata*
N Leach's storm-petrel, *Oceanodroma leucorhoa*
N ashy storm-petrel, *Oceanodroma homochroa*
wedge-rumped storm-petrel, *Oceanodroma tethys* - *

[1] It is unknown if California records pertain to the endangered Hawaiian dark-rumped petrel, *P. p. sandwichensis*, or the nominate subspecies of the Galapagos Islands (or both), although the former appears more likely.

N black storm-petrel, *Oceanodroma melania*
least storm-petrel, *Oceanodroma microsoma*

PELECANIFORMES - Totipalmate Swimmers

Phaethontidae - Tropicbirds
white-tailed tropicbird, *Phaethon lepturus* - *P
red-billed tropicbird, *Phaethon aethereus*
red-tailed tropicbird, *Phaethon rubricauda* - *P

Sulidae - Boobies and Gannets
masked booby, *Sula dactylatra* - *P
blue-footed booby, *Sula nebouxii* - *
brown booby, *Sula leucogaster* - *
red-footed booby, *Sula sula* - *

Pelecanidae - Pelicans
N American white pelican, *Pelecanus erythrorhynchos*
N brown pelican, *Pelecanus occidentalis*
N California brown pelican, *P. o. californicus* - SE, FE

Phalacrocoracidae - Cormorants
N Brandt's cormorant, *Phalacrocorax penicillatus*
n* neotropic cormorant, *Phalacrocorax brasilianus* - *P
N double-crested cormorant, *Phalacrocorax auritus*
N pelagic cormorant, *Phalacrocorax pelagicus*

Anhingidae - Darters
anhinga, *Anhinga anhinga* - *P

Fregatidae - Frigatebirds
magnificent frigatebird, *Fregata magnificens*
great frigatebird, *Fregata minor* - *P

CICONIIFORMES - Herons, Ibises, Storks, American Vultures, and Allies

Ardeidae - Bitterns and Herons
N American bittern, *Botaurus lentiginosus*
N least bittern, *Ixobrychus exilis*
N great blue heron, *Ardea herodias*
N great egret, *Ardea alba*
N snowy egret, *Egretta thula*
N little blue heron, *Egretta caerulea*
n^S tricolored heron, *Egretta tricolor* - *
reddish egret, *Egretta rufescens* - *
N cattle egret, *Bubulcus ibis*

N green heron, *Butorides virescens*
N black-crowned night-heron, *Nycticorax nycticorax*
n* yellow-crowned night-heron, *Nyctanassa violacea* - *

Threskiornithidae - Ibises and Spoonbills
white ibis, *Eudocimus albus* - *
N white-faced ibis, *Plegadis chihi*
roseate spoonbill, *Ajaia ajaja* - *

Ciconiidae - Storks
n* wood stork, *Mycteria americana* - FE[2]

Cathartidae - American Vultures
black vulture, *Coragyps atratus* - *P
N turkey vulture, *Cathartes aura*
(N)[3] California condor, *Gymnogyps californianus* - E[3], SE, FE

ANSERIFORMES - Screamers, Swans, Geese, and Ducks

Anatidae - Swans, Geese, and Ducks
black-bellied whistling-duck, *Dendrocygna autumnalis* - *P
N fulvous whistling-duck, *Dendrocygna bicolor*
greater white-fronted goose, *Anser albifrons*
emperor goose, *Chen canagica* - *
n snow goose, *Chen caerulescens*
Ross's goose, *Chen rossii*
N Canada goose, *Branta canadensis*
Aleutian Canada goose, *B. c. leucopareia* - FPD
brant, *Branta bernicla*
trumpeter swan, *Cygnus buccinator* - *P
tundra swan, *Cygnus columbianus*
whooper swan, *Cygnus cygnus* - *P
N wood duck, *Aix sponsa*
N gadwall, *Anas strepera*
Eurasian wigeon, *Anas penelope*
N American wigeon, *Anas americana*
American black duck, *Anas rubripes* - *
N mallard, *Anas platyrhynchos*

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[2] Status applies to U.S. breeding population only.

[3] The entire wild population was taken into captivity in 1987. Since 1992, individuals have been released into the wild in California and elsewhere. Although some birds currently are paired and others have shown courtship behavior, there is yet no known nesting. Because the wild population is not yet known to be viable, the CBRC still considers the species extirpated.

N blue-winged teal, *Anas discors*
N cinnamon teal, *Anas cyanoptera*
N northern shoveler, *Anas clypeata*
N northern pintail, *Anas acuta*
garganey, *Anas querquedula* - *
Baikal teal, *Anas formosa* - *
N green-winged teal, *Anas crecca*
N canvasback, *Aythya valisineria*
N redhead, *Aythya americana*
common pochard, *Aythya ferina* - *P
N ring-necked duck, *Aythya collaris*
tufted duck, *Aythya fuligula*
greater scaup, *Aythya marila*
N lesser scaup, *Aythya affinis*
Steller's eider, *Polysticta stelleri* - *
king eider, *Somateria spectabilis* - *
(N)n harlequin duck, *Histrionicus histrionicus*
surf scoter, *Melanitta perspicillata*
white-winged scoter, *Melanitta fusca*
black scoter, *Melanitta nigra*
long-tailed duck, *Clangula hyemalis*
N bufflehead, *Bucephala albeola*
common goldeneye, *Bucephala clangula*
n Barrow's goldeneye, *Bucephala islandica*
smew, *Mergellus albellus* - *P
n hooded merganser, *Lophodytes cucullatus*
N common merganser, *Mergus merganser*
red-breasted merganser, *Mergus serrator*
N ruddy duck, *Oxyura jamaicensis*

FALCONIFORMES - Diurnal Birds of Prey

Accipitridae - Kites, Eagles, Hawks, and Allies
N osprey, *Pandion haliaetus*
N white-tailed kite, *Elanus leucurus*
Mississippi kite, *Ictinia mississippiensis* - *
N bald eagle, *Haliaeetus leucocephalus* - SE, FPD
N northern harrier, *Circus cyaneus*
N sharp-shinned hawk, *Accipiter striatus*
N Cooper's hawk, *Accipiter cooperii*
N northern goshawk, *Accipiter gentilis*
common black-hawk, *Buteogallus anthracinus* - *S
n Harris's hawk, *Parabuteo unicinctus* - *
N red-shouldered hawk, *Buteo lineatus*

broad-winged hawk, *Buteo platypterus*
N Swainson's hawk, *Buteo swainsoni* - ST
n zone-tailed hawk, *Buteo albonotatus*
N red-tailed hawk, *Buteo jamaicensis*
n ferruginous hawk, *Buteo regalis*
rough-legged hawk, *Buteo lagopus*
N golden eagle, *Aquila chrysaetos*

Falconidae - Caracaras and Falcons
N American kestrel, *Falco sparverius*
merlin, *Falco columbarius*
gyrfalcon, *Falco rusticolus* - *
N peregrine falcon, *Falco peregrinus*
N American peregrine falcon, *F. p. anatum* - SE
N prairie falcon, *Falco mexicanus*

GALLIFORMES - Gallinaceous Birds

Phasianidae - Partridges, Grouse, and Turkeys
N ruffed grouse, *Bonasa umbellus*
N greater sage-grouse, *Centrocercus urophasianus*
N blue grouse, *Dendragapus obscurus*
(N) sharp-tailed grouse, *Tympanuchus phasianellus* - E

Odontophoridae - New World Quail
N mountain quail, *Oreortyx pictus*
N California quail, *Callipepla californica*
N Gambel's quail, *Callipepla gambelii*

GRUIFORMES - Cranes, Rails, and Allies

Rallidae - Rails, Gallinules, and Coots
(N) yellow rail, *Coturnicops noveboracensis* - *
N black rail, *Laterallus jamaicensis*
N California black rail, *L. j. coturniculus* - ST
N clapper rail, *Rallus longirostris*
N California clapper rail, *R. l. obsoletus* - SE, FE
N light-footed clapper rail, *R. l. levipes* - SE, FE
N Yuma clapper rail, *R. l. yumanensis* - ST, FE
N Virginia rail, *Rallus limicola*
N sora, *Porzana carolina*
purple gallinule, *Porphyrula martinica* - *
N common moorhen, *Gallinula chloropus*
N American coot, *Fulica americana*

Gruidae - Cranes
N sandhill crane, *Grus canadensis*
N greater sandhill crane, *G. c. tabida* - ST

CHARADRIIFORMES - Shorebirds, Gulls, Auks, and Allies

Charadriidae - Plovers and Lapwings
black-bellied plover, *Pluvialis squatarola*
American golden-plover, *Pluvialis dominica*
Pacific golden-plover, *Pluvialis fulva*
Mongolian plover, *Charadrius mongolus* - *P
N snowy plover, *Charadrius alexandrinus*
N western snowy plover, *C. a. nivosus* - FT(coastal population)
n Wilson's plover, *Charadrius wilsonia* - *
n semipalmated plover, *Charadrius semipalmatus*
piping plover, *Charadrius melodus* - *P, FT
N killdeer, *Charadrius vociferus*
mountain plover, *Charadrius montanus* - FPT
Eurasian dotterel, *Charadrius morinellus* - *PV

Haematopodidae - Oystercatchers
n[S] American oystercatcher, *Haematopus palliatus* - *
N black oystercatcher, *Haematopus bachmani*

Recurvirostridae - Stilts and Avocets
N black-necked stilt, *Himantopus mexicanus*
N American avocet, *Recurvirostra americana*

Scolopacidae - Sandpipers, Phalaropes, and Allies
greater yellowlegs, *Tringa melanoleuca*
lesser yellowlegs, *Tringa flavipes*
spotted redshank, *Tringa erythropus* - *P
solitary sandpiper, *Tringa solitaria*
N willet, *Catoptrophorus semipalmatus*
wandering tattler, *Heteroscelus incanus*
gray-tailed tattler, *Heteroscelus brevipes* - *P
N spotted sandpiper, *Actitis macularia*
Terek sandpiper, *Xenus cinereus* - *PV
upland sandpiper, *Bartramia longicauda* - *
little curlew, *Numenius minutus* - *P
bristle-thighed curlew, *Numenius tahitiensis* - *PV
whimbrel, *Numenius phaeopus*
N long-billed curlew, *Numenius americanus*
Hudsonian godwit, *Limosa haemastica* - *P
bar-tailed godwit, *Limosa lapponica* - *

marbled godwit, *Limosa fedoa*
ruddy turnstone, *Arenaria interpres*
black turnstone, *Arenaria melanocephala*
surfbird, *Aphriza virgata*
red knot, *Calidris canutus*
sanderling, *Calidris alba*
semipalmated sandpiper, *Calidris pusilla*
western sandpiper, *Calidris mauri*
red-necked stint, *Calidris ruficollis* - *P
little stint, *Calidris minuta* - *
long-toed stint, *Calidris subminuta* - *P
least sandpiper, *Calidris minutilla*
white-rumped sandpiper, *Calidris fuscicollis* - *
Baird's sandpiper, *Calidris bairdii*
pectoral sandpiper, *Calidris melanotos*
sharp-tailed sandpiper, *Calidris acuminata*
rock sandpiper, *Calidris ptilocnemis*
dunlin, *Calidris alpina*
curlew sandpiper, *Calidris ferruginea* - *
stilt sandpiper, *Calidris himantopus*
buff-breasted sandpiper, *Tryngites subruficollis*
ruff, *Philomachus pugnax*
short-billed dowitcher, *Limnodromus griseus*
long-billed dowitcher, *Limnodromus scolopaceus*
jack snipe, *Lymnocryptes minimus* - *
N common snipe, *Gallinago gallinago*
American woodcock, *Scolopax minor* - *P
N Wilson's phalarope, *Phalaropus tricolor*
red-necked phalarope, *Phalaropus lobatus*
red phalarope, *Phalaropus fulicaria*

Laridae - Skuas, Gulls, Terns, and Skimmers
south polar skua, *Stercorarius maccormicki*
pomarine jaeger, *Stercorarius pomarinus*
parasitic jaeger, *Stercorarius parasiticus*
long-tailed jaeger, *Stercorarius longicaudus*
n laughing gull, *Larus atricilla*
n Franklin's gull, *Larus pipixcan*
little gull, *Larus minutus* - *
black-headed gull, *Larus ridibundus* - *P
Bonaparte's gull, *Larus philadelphia*
n Heermann's gull, *Larus heermanni*
band-tailed gull, *Larus belcheri* - *PV
black-tailed gull, *Larus crassirostris* - *

mew gull, *Larus canus*
N ring-billed gull, *Larus delawarensis*
N California gull, *Larus californicus*
herring gull, *Larus argentatus*
Thayer's gull, *Larus thayeri*
Iceland gull, *Larus glaucoides* - *P
lesser black-backed gull, *Larus fuscus* - *P
yellow-footed gull, *Larus livens*
N western gull, *Larus occidentalis*
n* glaucous-winged gull, *Larus glaucescens*
glaucous gull, *Larus hyperboreus*
Sabine's gull, *Xema sabini*
swallow-tailed gull, *Creagrus furcatus* - *P
black-legged kittiwake, *Rissa tridactyla*
red-legged kittiwake, *Rissa brevirostris* - *
ivory gull, *Pagophila eburnea* - *P
N gull-billed tern, *Sterna nilotica*
N Caspian tern, *Sterna caspia*
N royal tern, *Sterna maxima*
N elegant tern, *Sterna elegans*
n* Sandwich tern, *Sterna sandvicensis* - *P
common tern, *Sterna hirundo*
n* arctic tern, *Sterna paradisaea*
N Forster's tern, *Sterna forsteri*
N least tern, *Sterna antillarum*
N California least tern, *S. a. browni* - SE, FE
bridled tern, *Sterna anaethetus* -*S
n sooty tern, *Sterna fuscata* - *
white-winged tern, *Chlidonias leucopterus* - *P
N black tern, *Chlidonias niger*
N black skimmer, *Rynchops niger*

Alcidae - Auks, Murres, and Puffins
N common murre, *Uria aalge*
thick-billed murre, *Uria lomvia* - *
N pigeon guillemot, *Cepphus columba*
long-billed murrelet, *Brachyramphus perdix* - *
N marbled murrelet, *Brachyramphus marmoratus* - SE, FT
Kittlitz's murrelet, *Brachyramphus brevirostris* - *
N Xantus's murrelet, *Synthliboramphus hypoleucus*
Craveri's murrelet, *Synthliboramphus craveri*
ancient murrelet, *Synthliboramphus antiquus*
N Cassin's auklet, *Ptychoramphus aleuticus*
parakeet auklet, *Aethia psittacula* - *

least auklet, *Aethia pusilla* - *
crested auklet, *Aethia cristatella* - *
N rhinoceros auklet, *Cerorhinca monocerata*
horned puffin, *Fratercula corniculata*
N tufted puffin, *Fratercula cirrhata*

COLUMBIFORMES - Pigeons and Doves

Columbidae - Pigeons and Doves
N band-tailed pigeon, *Columba fasciata*
N white-winged dove, *Zenaida asiatica*
N mourning dove, *Zenaida macroura*
N Inca dove, *Columbina inca*
N common ground-dove, *Columbina passerina*
n[5] ruddy ground-dove, *Columbina talpacoti* - *

CUCULIFORMES - Cuckoos, and Allies

Cuculidae - Cuckoos, Roadrunners, and Anis
black-billed cuckoo, *Coccyzus erythropthalmus* - *
N yellow-billed cuckoo, *Coccyzus americanus*
N western yellow-billed cuckoo, *C. a. occidentalis* - SE
N greater roadrunner, *Geococcyx californianus*
groove-billed ani, *Crotophaga sulcirostris* - *P

STRIGIFORMES - Owls

Tytonidae - Barn Owls
N barn owl, *Tyto alba*

Strigidae - Typical Owls
N flammulated owl, *Otus flammeolus*
N western screech-owl, *Otus kennicottii*
N great horned owl, *Bubo virginianus*
snowy owl, *Nyctea scandiaca* - *
N northern pygmy-owl, *Glaucidium gnoma*
N elf owl, *Micrathene whitneyi* - SE
N burrowing owl, *Athene cunicularia*
N spotted owl, *Strix occidentalis*
N northern spotted owl, *S. o. caurina* - FT
N barred owl, *Strix varia* - PT
N great gray owl, *Strix nebulosa* - SE
N long-eared owl, *Asio otus*
N short-eared owl, *Asio flammeus*
N northern saw-whet owl, *Aegolius acadicus*

CAPRIMULGIFORMES - Goatsuckers, Oilbirds, and Allies

Caprimulgidae - Goatsuckers

N lesser nighthawk, *Chordeiles acutipennis*
N common nighthawk, *Chordeiles minor*
N common poorwill, *Phalaenoptilus nuttallii*
chuck-will's-widow, *Caprimulgus carolinensis* - *
buff-collared nightjar, *Caprimulgus ridgwayi* - *
N[S] whip-poor-will, *Caprimulgus vociferus*

APODIFORMES - Swifts, and Hummingbirds

Apodidae - Swifts

N black swift, *Cypseloides niger*
white-collared swift, *Streptoprocne zonaris* - *S
n chimney swift, *Chaetura pelagica*
N Vaux's swift, *Chaetura vauxi*
N white-throated swift, *Aeronautes saxatalis*

Trochilidae - Hummingbirds

broad-billed hummingbird, *Cynanthus latirostris* - *P
n* Xantus's hummingbird, *Hylocharis xantusii* - *P
violet-crowned hummingbird, *Amazilia violiceps* - *P
n* blue-throated hummingbird, *Lampornis clemenciae* - *P
ruby-throated hummingbird, *Archilochus colubris* - *
N black-chinned hummingbird, *Archilochus alexandri*
N Anna's hummingbird, *Calypte anna*
N Costa's hummingbird, *Calypte costae*
N calliope hummingbird, *Stellula calliope*
N broad-tailed hummingbird, *Selasphorus platycercus*
n rufous hummingbird, *Selasphorus rufus*
N Allen's hummingbird, *Selasphorus sasin*

CORACIIFORMES - Kingfishers, Rollers, Hornbills, and Allies

Alcedinidae - Kingfishers

N belted kingfisher, *Ceryle alcyon*

PICIFORMES - Puffbirds, Toucans, Woodpeckers, and Allies

Picidae - Woodpeckers and Allies

N Lewis's woodpecker, *Melanerpes lewis*
red-headed woodpecker, *Melanerpes erythrocephalus* - *
N acorn woodpecker, *Melanerpes formicivorus*
N Gila woodpecker, *Melanerpes uropygialis* - SE
N Williamson's sapsucker, *Sphyrapicus thyroideus*

yellow-bellied sapsucker, *Sphyrapicus varius*
N red-naped sapsucker, *Sphyrapicus nuchalis*
N red-breasted sapsucker, *Sphyrapicus ruber*
N ladder-backed woodpecker, *Picoides scalaris*
N Nuttall's woodpecker, *Picoides nuttallii*
N downy woodpecker, *Picoides pubescens*
N hairy woodpecker, *Picoides villosus*
N white-headed woodpecker, *Picoides albolarvatus*
three-toed woodpecker, *Picoides tridactylus* - *S
N black-backed woodpecker, *Picoides arcticus*
N northern flicker, *Colaptes auratus*
N gilded flicker, *Colaptes chrysoides* - SE[4]
N pileated woodpecker, *Dryocopus pileatus*

PASSERIFORMES - Passerine Birds

Tyrannidae - Tyrant Flycatchers
N olive-sided flycatcher, *Contopus cooperi*
greater pewee, *Contopus pertinax* - *
N western wood-pewee, *Contopus sordidulus*
eastern wood-pewee, *Contopus virens* - *PT
yellow-bellied flycatcher, *Empidonax flaviventris* - *
alder flycatcher, *Empidonax alnorum* - *T
N willow flycatcher, *Empidonax traillii* - SE
N southwestern willow flycatcher, *E. t. extimus* - FE
n least flycatcher, *Empidonax minimus*
N Hammond's flycatcher, *Empidonax hammondii*
N gray flycatcher, *Empidonax wrightii*
N dusky flycatcher, *Empidonax oberholseri*
N Pacific-slope flycatcher, *Empidonax difficilis*
N cordilleran flycatcher, *Empidonax occidentalis*
N black phoebe, *Sayornis nigricans*
eastern phoebe, *Sayornis phoebe*
N Say's phoebe, *Sayornis saya*
N vermilion flycatcher, *Pyrocephalus rubinus*
dusky-capped flycatcher, *Myiarchus tuberculifer* - *
N ash-throated flycatcher, *Myiarchus cinerascens*
great crested flycatcher, *Myiarchus crinitus* - *
N brown-crested flycatcher, *Myiarchus tyrannulus*
sulphur-bellied flycatcher, *Myiodynastes luteiventris* - *PV

[4] Formerly considered conspecific with the northern flicker, and still erroneously called gilded northern flicker, *Colaptes auratus chrysoides*, by the State of California. The subspecies in California is *C.* [*auratus*] *chrysoides mearnsi*; *C.*[*auratus*] *c. chrysoides* is endemic to the southern half of the Baja California peninsula.

tropical kingbird, *Tyrannus melancholicus*
Couch's kingbird, *Tyrannus couchii* - *P
N Cassin's kingbird, *Tyrannus vociferans*
thick-billed kingbird, *Tyrannus crassirostris* - *PT
N western kingbird, *Tyrannus verticalis*
n eastern kingbird, *Tyrannus tyrannus*
n* scissor-tailed flycatcher, *Tyrannus forficatus*
fork-tailed flycatcher, *Tyrannus savana* - *P

Laniidae - Shrikes
brown shrike, *Lanius cristatus* - *P
N loggerhead shrike, *Lanius ludovicianus*
(N)[5] San Clemente loggerhead shrike, *L. l. mearnsi* - FE
northern shrike, *Lanius excubitor*

Vireonidae - Vireos
white-eyed vireo, *Vireo griseus* - *PT
N Bell's vireo, *Vireo bellii*
N Arizona Bell's vireo, *V. b. arizonae* - SE
N least Bell's vireo, *V. b. pusillus* - SE, FE
N gray vireo, *Vireo vicinior*
yellow-throated vireo, *Vireo flavifrons* - *
N plumbeous vireo, *Vireo plumbeus*
N Cassin's vireo, *Vireo cassinii*
blue-headed vireo, *Vireo solitarius* - *
N Hutton's vireo, *Vireo huttoni*
N warbling vireo, *Vireo gilvus*
Philadelphia vireo, *Vireo philadelphicus*
n red-eyed vireo, *Vireo olivaceus*
yellow-green vireo, *Vireo flavoviridis* - *

Corvidae - Jays, Magpies, and Crows
N gray jay, *Perisoreus canadensis*
N Steller's jay, *Cyanocitta stelleri*
blue jay, *Cyanocitta cristata* - *
N island scrub-jay, *Aphelocoma insularis*
N western scrub-jay, *Aphelocoma californica*
N pinyon jay, *Gymnorhinus cyanocephalus*

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[5]Although *L.l. mearnsi* is a valid subspecies, shrikes on San Clemente Island may no longer show its characters. Instead, they may be intermediate between it and *L. l. anthonyi* of the northern Channel Islands (M.A. Patten and K.F. Campbell. 2000. Typological thinking and the conservation of subspecies: The case of the San Clemente Island Shrike. Diversity and Distributions, Vol. 6.).

N Clark's nutcracker, *Nucifraga columbiana*
N black-billed magpie, *Pica hudsonia*
N yellow-billed magpie, *Pica nuttalli*
N American crow, *Corvus brachyrhynchos*
N common raven, *Corvus corax*

Alaudidae - Larks
sky lark, *Alauda arvensis* - *P
N horned lark, *Eremophila alpestris*

Hirundinidae - Swallows
N purple martin, *Progne subis*
N tree swallow, *Tachycineta bicolor*
N violet-green swallow, *Tachycineta thalassina*
N northern rough-winged swallow, *Stelgidopteryx serripennis*
N bank swallow, *Riparia riparia* - ST
N cliff swallow, *Petrochelidon pyrrhonota*
cave swallow, *Petrochelidon fulva* - *P
N barn swallow, *Hirundo rustica*

Paridae - Titmice
N black-capped chickadee, *Poecile atricapilla*
N mountain chickadee, *Poecile gambeli*
N chestnut-backed chickadee, *Poecile rufescens*
N oak titmouse, *Baeolophus inornatus*
N juniper titmouse, *Baeolophus ridgwayi*

Remizidae - Penduline Tits and Verdins
N verdin, *Auriparus flaviceps*

Aegithalidae - Long-tailed Tits and Bushtits
N bushtit, *Psaltriparus minimus*

Sittidae - Nuthatches
N red-breasted nuthatch, *Sitta canadensis*
N white-breasted nuthatch, *Sitta carolinensis*
N pygmy nuthatch, *Sitta pygmaea*

Certhiidae - Creepers
N brown creeper, *Certhia americana*

Troglodytidae - Wrens
N cactus wren, *Campylorhynchus brunneicapillus*
N rock wren, *Salpinctes obsoletus*
N canyon wren, *Catherpes mexicanus*
N Bewick's wren, *Thryomanes bewickii*

N house wren, *Troglodytes aedon*
N winter wren, *Troglodytes troglodytes*
sedge wren, *Cistothorus platensis* - *PT
N marsh wren, *Cistothorus palustris*

Cinclidae - Dippers
N American dipper, *Cinclus mexicanus*

Regulidae - Kinglets
N golden-crowned kinglet, *Regulus satrapa*
N ruby-crowned kinglet, *Regulus calendula*

Sylviidae - Old World Warblers and Gnatcatchers
lanceolated warbler, *Locustella lanceolata* - *P
dusky warbler, *Phylloscopus fuscatus* - *
arctic warbler, *Phylloscopus borealis* - *P
N blue-gray gnatcatcher, *Polioptila caerulea*
N California gnatcatcher, *Polioptila californica*
N coastal California gnatcatcher, *P. c. californica* - FT
N black-tailed gnatcatcher, *Polioptila melanura*

Turdidae - Solitaires, Thrushes, and Allies
red-flanked bluetail, *Tarsiger cyanurus* - *P
northern wheatear, *Oenanthe oenanthe* - *
N western bluebird, *Sialia mexicana*
N mountain bluebird, *Sialia currucoides*
N Townsend's solitaire, *Myadestes townsendi*
veery, *Catharus fuscescens* - *P
gray-cheeked thrush, *Catharus minimus* - *
N Swainson's thrush, *Catharus ustulatus*
N hermit thrush, *Catharus guttatus*
wood thrush, *Hylocichla mustelina* - *
rufous-backed robin, *Turdus rufopalliatus* - *P
N American robin, *Turdus migratorius*
N varied thrush, *Ixoreus naevius*

Timaliidae - Babblers
N wrentit, *Chamaea fasciata*

Mimidae - Mockingbirds, Thrashers, and Allies
gray catbird, *Dumetella carolinensis*
N northern mockingbird, *Mimus polyglottos*
N sage thrasher, *Oreoscoptes montanus*
brown thrasher, *Toxostoma rufum*
N Bendire's thrasher, *Toxostoma bendirei*

curve-billed thrasher, *Toxostoma curvirostre* - *
N California thrasher, *Toxostoma redivivum*
N crissal thrasher, *Toxostoma crissale*
N Le Conte's thrasher, *Toxostoma lecontei*

Motacillidae - Wagtails and Pipits
yellow wagtail, *Motacilla flava* - *P
gray wagtail, *Motacilla cinerea* - *P
white wagtail, *Motacilla alba* - *P
black-backed wagtail, *Motacilla lugens* - *PV
olive-backed pipit, *Anthus hodgsoni* - *P
red-throated pipit, *Anthus cervinus*
N American pipit, *Anthus rubescens*
Sprague's pipit, *Anthus spragueii* - *

Bombycillidae - Waxwings
Bohemian waxwing, *Bombycilla garrulus*
N cedar waxwing, *Bombycilla cedrorum*

Ptilogonatidae - Silky-flycatchers
N phainopepla, *Phainopepla nitens*

Parulidae - Wood-Warblers
blue-winged warbler, *Vermivora pinus* - *
golden-winged warbler, *Vermivora chrysoptera* - *
Tennessee warbler, *Vermivora peregrina*
N orange-crowned warbler, *Vermivora celata*
N Nashville warbler, *Vermivora ruficapilla*
N Virginia's warbler, *Vermivora virginiae*
N Lucy's warbler, *Vermivora luciae*
N northern parula, *Parula americana*
N yellow warbler, *Dendroica petechia*
chestnut-sided warbler, *Dendroica pensylvanica*
magnolia warbler, *Dendroica magnolia*
Cape May warbler, *Dendroica tigrina*
black-throated blue warbler, *Dendroica caerulescens*
N yellow-rumped warbler, *Dendroica coronata*
N black-throated gray warbler, *Dendroica nigrescens*
golden-cheeked warbler, *Dendroica chrysoparia* - * FE
black-throated green warbler, *Dendroica virens*
Townsend's warbler, *Dendroica townsendi*
N hermit warbler, *Dendroica occidentalis*
Blackburnian warbler, *Dendroica fusca*
n* yellow-throated warbler, *Dendroica dominica* - *
Grace's warbler, *Dendroica graciae* - *

pine warbler, *Dendroica pinus* - *
prairie warbler, *Dendroica discolor*
palm warbler, *Dendroica palmarum*
bay-breasted warbler, *Dendroica castanea*
blackpoll warbler, *Dendroica striata*
cerulean warbler, *Dendroica cerulea* - *
black-and-white warbler, *Mniotilta varia*
N American redstart, *Setophaga ruticilla*
prothonotary warbler, *Protonotaria citrea*
worm-eating warbler, *Helmitheros vermivorus* - *
ovenbird, *Seiurus aurocapillus*
northern waterthrush, *Seiurus noveboracensis*
Louisiana waterthrush, *Seiurus motacilla* - *
Kentucky warbler, *Oporornis formosus*
Connecticut warbler, *Oporornis agilis* - *
mourning warbler, *Oporornis philadelphia* - *
N MacGillivray's warbler, *Oporornis tolmiei*
N common yellowthroat, *Geothlypis trichas*
n hooded warbler, *Wilsonia citrina*
N Wilson's warbler, *Wilsonia pusilla*
Canada warbler, *Wilsonia canadensis*
red-faced warbler, *Cardellina rubrifrons* - *
n painted redstart, *Myioborus pictus*
N yellow-breasted chat, *Icteria virens*

Thraupidae - Tanagers
N hepatic tanager, *Piranga flava*
N summer tanager, *Piranga rubra*
scarlet tanager, *Piranga olivacea* - *
N western tanager, *Piranga ludoviciana*

Emberizidae - Emberizines
N green-tailed towhee, *Pipilo chlorurus*
N spotted towhee, *Pipilo maculatus*
N California towhee, *Pipilo crissalis*
N Inyo California towhee, *P. c. eremophilus* - SE, FT
N Abert's towhee, *Pipilo aberti*
Cassin's sparrow, *Aimophila cassinii* - *
N rufous-crowned sparrow, *Aimophila ruficeps*
American tree sparrow, *Spizella arborea*
N chipping sparrow, *Spizella passerina*
clay-colored sparrow, *Spizella pallida*
N Brewer's sparrow, *Spizella breweri*
field sparrow, *Spizella pusilla* - *P
N black-chinned sparrow, *Spizella atrogularis*

N vesper sparrow, *Pooecetes gramineus*
N lark sparrow, *Chondestes grammacus*
N black-throated sparrow, *Amphispiza bilineata*
N sage sparrow, *Amphispiza belli*
N San Clemente sage sparrow, *A. b. clementeae* - FT
n lark bunting, *Calamospiza melanocorys*
N Savannah sparrow, *Passerculus sandwichensis*
N Belding's Savannah sparrow, *P. s. beldingi* - SE
N grasshopper sparrow, *Ammodramus savannarum*
Baird's sparrow, *Ammodramus bairdii* - *
Le Conte's sparrow, *Ammodramus leconteii* - *
Nelson's sharp-tailed sparrow, *Ammodramus nelsoni*
N fox sparrow, *Passerella iliaca*
N song sparrow, *Melospiza melodia*
N Lincoln's sparrow, *Melospiza lincolnii*
swamp sparrow, *Melospiza georgiana*
white-throated sparrow, *Zonotrichia albicollis*
Harris's sparrow, *Zonotrichia querula*
N white-crowned sparrow, *Zonotrichia leucophrys*
golden-crowned sparrow, *Zonotrichia atricapilla*
N dark-eyed junco, *Junco hyemalis*
McCown's longspur, *Calcarius mccownii*
Lapland longspur, *Calcarius lapponicus*
Smith's longspur, *Calcarius pictus* - *PV
chestnut-collared longspur, *Calcarius ornatus*
little bunting, *Emberiza pusilla* - *P
rustic bunting, *Emberiza rustica* - *P
snow bunting, *Plectrophenax nivalis* - *

Cardinalidae - Cardinals, Grosbeaks, and Allies
N northern cardinal, *Cardinalis cardinalis*
n pyrrhuloxia, *Cardinalis sinuatus* - *P
n* rose-breasted grosbeak, *Pheucticus ludovicianus*
N black-headed grosbeak, *Pheucticus melanocephalus*
N blue grosbeak, *Guiraca caerulea*
N lazuli bunting, *Passerina amoena*
N indigo bunting, *Passerina cyanea*
varied bunting, *Passerina versicolor* - *
painted bunting, *Passerina ciris* - *
dickcissel, *Spiza americana*

Icteridae - Blackbirds and Allies
n[S] bobolink, *Dolichonyx oryzivorus*
N red-winged blackbird, *Agelaius phoeniceus*
N tricolored blackbird, *Agelaius tricolor*

N western meadowlark, *Sturnella neglecta*
N yellow-headed blackbird, *Xanthocephalus xanthocephalus*
rusty blackbird, *Euphagus carolinus*
N Brewer's blackbird, *Euphagus cyanocephalus*
common grackle, *Quiscalus quiscula* - *
N great-tailed grackle, *Quiscalus mexicanus*
N bronzed cowbird, *Molothrus aeneus*
N brown-headed cowbird, *Molothrus ater*
orchard oriole, *Icterus spurius*
N hooded oriole, *Icterus cucullatus*
streak-backed oriole, *Icterus pustulatus* - *
N Bullock's oriole, *Icterus bullockii*
Baltimore oriole, *Icterus galbula*
N Scott's oriole, *Icterus parisorum*

Fringillidae - Fringilline and Cardueline Finches and Allies
brambling, *Fringilla montifringilla* - *PV
N gray-crowned rosy-finch, *Leucosticte tephrocotis*
black rosy-finch, *Leucosticte atrata* - *
N pine grosbeak, *Pinicola enucleator*
N purple finch, *Carpodacus purpureus*
N Cassin's finch, *Carpodacus cassinii*
N house finch, *Carpodacus mexicanus*
N red crossbill, *Loxia curvirostra*
white-winged crossbill, *Loxia leucoptera* - *S
common redpoll, *Carduelis flammea* - *
N pine siskin, *Carduelis pinus*
N lesser goldfinch, *Carduelis psaltria*
N Lawrence's goldfinch, *Carduelis lawrencei*
N American goldfinch, *Carduelis tristis*
N evening grosbeak, *Coccothraustes vespertinus*

WELL-ESTABLISHED NON-NATIVE SPECIES

GALLIFORMES - Gallinaceous Birds

Phasianidae - Partridges, Grouse, and Turkeys
N chukar, *Alectoris chukar* - I
N ring-necked pheasant, *Phasianus colchicus* - I
N white-tailed ptarmigan, *Lagopus leucurus* - IP
N wild turkey, *Meleagris gallopavo* - I

COLUMBIFORMES - Sandgrouse, Pigeons, and Doves

Columbidae - Pigeons and Doves
N rock dove, *Columba livia* - I

N spotted dove, *Streptopelia chinensis* - I

PASSERIFORMES - Passerine Birds

Sturnidae - Starlings and Allies
N European starling, *Sturnus vulgaris* - I

Passeridae - Old World Sparrows
N house sparrow, *Passer domesticus* - I

ADDITIONAL NATURALIZED SPECIES NOT YET REVIEWED OR ACCEPTED BY THE CBRC

ANSERIFORMES - Screamers, Swans, Geese, and Ducks

Anatidae - Swans, Geese, and Ducks
N Egyptian goose, *Alopochen aegyptiacus* - I
N mute swan, *Cygnus olor* - I
N Mandarin duck, *Aix galericulata* - I

GALLIFORMES - Gallinaceous Birds

Phasianidae - Partridges, Grouse, and Turkeys
N common peafowl, *Pavo cristatus* - I

COLUMBIFORMES - Sandgrouse, Pigeons, and Doves

Columbidae - Pigeons and Doves
N Eurasian collared-dove, *Streptopelia decaocto* - I

PSITTACIFORMES - Parrots

Psittacidae - Lories, Parakeets, Macaws, and Parrots
N rose-ringed parakeet, *Psittacula krameri* - I
N blue-crowned parakeet, *Aratinga acuticaudata* - I
N mitred parakeet, *Aratinga mitrata* - I
N red-masked parakeet, *Aratinga erythrogenys* - I
N black-hooded parakeet, *Nandayus nenday* - I
N white-winged parakeet, *Brotogeris versicolurus* - I
N yellow-chevroned parakeet, *Brotogeris chiriri* - I
N red-crowned parrot, *Amazona viridigenalis* - I
N lilac-crowned parrot, *Amazona finschi* - I
N yellow-headed parrot, *Amazona oratrix* - I

PASSERIFORMES - Passerine Birds

Ploceidae - Weavers
N orange bishop, *Euplectes franciscanus* - I

Estrildidae - Estrildid Finches
N nutmeg mannikin, *Lonchura punctulata* - I

SUPPLEMENTAL LIST

This list includes those species recorded in California for which the CBRC has determined that all records are of uncertain natural occurrence. Thus, the CBRC could not reach a consensus judgement, given available evidence, as to whether or not records of these species involved true vagrants or escapes from captivity. Species with questionable natural occurrence (those judged by the CBRC to be escapees) are not admitted to the Supplemental List.

ANSERIFORMES - Screamers, Swans, Geese, and Ducks

Anatidae - Swans, Geese, and Ducks
falcated duck, *Anas falcata* - *P

FALCONIFORMES - Diurnal Birds of Prey

Falconidae - Caracaras and Falcons
crested caracara, *Caracara cheriway* - *P

PASSERIFORMES - Passerine Birds

Ptilogonatidae - Silky-flycatchers
gray silky-flycatcher, *Ptilogonys cinereus* - *PV

Fringillidae - Fringilline and Cardueline Finches and Allies
oriental greenfinch, *Carduelis sinica* - *P

Received: 3 April 2000
Accepted: 25 July 2000

California Fish and Game 86(3):208-212 2000

PRELIMINARY OBSERVATIONS OF THE BEHAVIOR OF MALE, FLAT-TAILED HORNED LIZARDS BEFORE AND AFTER AN OFF-HIGHWAY VEHICLE RACE IN CALIFORNIA

NANCY C. NICOLAI[1]
Bureau of Land Management
El Centro Resource Area
1661 South 4th Street,
El Centro, California 92243

JEFFREY E. LOVICH[2]
United States Geological Survey
Western Ecological Research Center
California State University
6000 J Street, Placer Hall
Sacramento, California 95819-6129
e-mail: jeffrey_lovich@usgs.gov

Animal movements are influenced by many factors, including the need for food and other resources necessary for survival; searching for mates or nest and brood sites; and response to stress, including escape from predators and environmental extremes. Although it is often difficult to determine the exact cause for particular movements by animals, movement, nonetheless, reflects an organism's response to its immediate and changing environment.

The flat-tailed horned lizard, *Phrynosoma mcallii*, is found in extreme southern California, southwestern Arizona, and northwestern Mexico. It was proposed for listing as a threatened species under the federal Endangered Species Act, but the proposal was withdrawn (USFWS[3] 1997). A variety of threats were identified in the listing proposal, including habitat destruction and direct mortality due to off-highway vehicle (OHV) activity. Large areas of habitat occupied by flat-tailed horned lizards are negatively impacted by OHV activity (Lovich and Bainbridge 1999). In addition to direct impacts, OHV activity may modify the behavior and, possibly, habitat use of this species (Wone and Beauchamp 1995, Beauchamp et al. 1998). In this paper we compare the rates of movement, activity areas, and mean vectors of movement of 3 radio-tagged, male, flat-tailed horned lizards before and after an OHV race.

The Yuha Desert study site (36°32'N, 115°51'W) is located in the western portion of the Colorado Desert (Burk 1977) of southeastern California. The area is managed

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[1] Current address: Department of Rangeland Ecology and Management, Animal Industries Building, Texas A&M University, College Station, Texas 77843-2126.

[2] Corresponding author.

[3] USFWS (United States Fish and Wildlife Service). 1997. Withdrawal of the proposed rule to list the flat-tailed horned lizard as threatened. Federal Register 62:37852-37860.

by the U.S. Bureau of Land Management, as an "Open Area" – a place where OHVs may travel both on and off roads and trails.

Vegetation at the study site was dominated by creosote bush, *Larrea tridentata;* burro-bush, *Ambrosia dumosa*; and scattered ocotillo, *Fouquieria splendens*. Total shrub cover was <5%. Small washes braided throughout the site and were dominated by burro-bush; galleta grass, *Pleuraphis rigida*; dyeweed, *Psorothamnus emoryi*; desert holly, *Atriplex hymenelytra*; and allscale, *A. polycarpa*. Plant cover in the washes averaged about 25%. Soils outside the washes were characterized by sand, small pebbles, and occasional cracked clay lenses. Wash soils were composed of coarse sand and gravel.

The core of the study site was bisected by a race course that is used as an OHV trail throughout the year. The race is called "24 hours of LeFud" and lasts from 0700 hours to 0700 hours the following morning (4–5 May 1996). Dune buggies, motorcycles, and other OHV's participate in this biennial event. Twenty-four hours prior to the race about 10 participants practiced the course throughout the day. The race began with approximately 50 participants traveling through the study plot about once every 20 minutes. Only 4–6 vehicles completed the race.

Before the race, 3 male, flat-tailed horned lizards were fitted with radio transmitters and released at the point of capture. The lizards weighed 13.5, 18.0, and 19.0 g and were 74, 71, and 74 mm snout-vent length, respectively. All were assumed to be adults (Turner and Medica 1982). Transmitters were attached with backpack harnesses following the method of Fisher and Muth (1995).

Lizards were monitored for 8–10 days before the race and 10 days after it. Locations of lizards were recorded at least once every other day, but usually twice per day (once before 1000 hours and once after 1500 hours) using a handheld global positioning system. Coordinates were differentially corrected to an accuracy of ±3 m. In addition to measuring distance between recaptures (meters), compass bearings were taken from the actual point of last relocation to the next relocation point. Wind speed, air temperature (1 cm above the ground), and relative humidity were measured each time a lizard was relocated.

As the time interval between relocations varied both among lizards and before and after the race, data on movement were standardized for statistical analysis to rates expressed as m/hour. A randomized-block ANOVA, blocking on individual lizards, was used to test for differences in movement rates before and after the race. Data were log-transformed to normalize them prior to analysis. Because compass direction is a circular scale variable, compass bearings between consecutive recaptures were analyzed separately using Oriana© software for circular statistics. Muth and Fisher[4] (1992) estimated that as many as 70 recaptures were required to adequately describe the home range of flat-tailed horned lizards. As relocations ranged from 10 to 16 for each lizard in each sampling interval (before or after the race), we chose the term "activity area" to describe the areas occupied by the lizards. Activity

[4]Muth, A. and M. Fisher. 1992. Development of baseline data and procedures for monitoring populations of the flat-tailed horned lizard. Final Report for Contract FG 9268, California Department of Fish and Game, Sacramento, California, USA.

area size was estimated using CALHOME shareware (Kie et al. 1996). We used the minimum convex polygon that encompassed all the observed locations for an animal during a given sampling interval (before or after the race event). Other statistical analyses were conducted using SYSTAT (Wilkinson 1988). Given the sensitive conservation status of the lizard and our small sample size, alpha was set at 0.10 to minimize the probability of "accepting" a false null hypothesis that OHV activity had no effect on lizard behavior.

Climatic conditions were similar before and after the race. Air temperatures ranged from 21 to 49°C and were not significantly different before and after the race ($F = 0.32$; $df = 1,68$; $P = 0.58$). Rates of movement before the race ($n = 36$) ranged from 0 to 21.2 m/hour with a mean of 3.6 m/hour (SD = 5.4). After the race, movements ($n = 40$) ranged from 0 to 16.5 m/hour with a mean of 2.4 m/hour (SD = 3.6). Mean log-transformed rates of movement before and after the race (1 case deleted due to no movement) differed significantly ($P = 0.085$), after blocking for the significant effect ($P < 0.001$) of individuals (Table 1). Distances moved between consecutive relocations varied with no obvious pattern related to the race. Activity area size increased for lizard #266, decreased for lizard #936, and remained about the same for lizard #17 following the race (Table 2). Rates of movement were not significantly correlated with wind speed or relative humidity, but were significantly correlated with air temperature ($r = -0.289$, $P = 0.083$).

Direction of movement between relocations before and after the race also varied significantly (Watson's F-test for 2 circular means, $F = 15.6$, $df = 74$, $P < 0.01$). Prior to the race, movements were almost uniform, as shown by a wide 95% confidence interval (65.3° clockwise to 15.4°) for a mean vector of 220.3°. After the race, movement directions were still highly variable, but the 95% confidence

Table 1. Randomized-block ANOVA for log-transformed data on rates of movement (m/hour) of 3 radio-tagged, male, flat-tailed horned lizards before and after (treatment) an off-highway vehicle race. Blocking is on individuals.

Source	Sum of squares	DF	Mean square	F-ratio	*P*
Block	39.790	2	19.895	13.887	<0.001
Treatment	4.384	1	4.384	3.060	0.085
Error	101.717	71	1.433		

Table 2. Summary of movements of male, flat-tailed horned lizards before and after an off-highway vehicle race. Activity areas are based on minimum convex polygons. Sample sizes are given in parentheses.

	Mean distance (m) between sequential recaptures		Activity area size (m^2)	
Lizard ID #	Before	After	Before	After
17	71.7 (14)	53.8 (12)	14,450	11,190
266	32.6 (11)	131.7 (10)	2,708	65,390
936	18.3 (15)	6.3 (15)	3,776	75

interval (255.7° clockwise to 118.3°) was reduced and the mean vector of movement shifted to 7°.

OHV activity impacts desert animals (Webb and Wilshire 1983, Brooks 1995) in various ways, including hearing loss in some lizards (Brattstrom and Bondello 1983). Others have noticed decreased abundance of desert reptiles in areas used by OHVs (Busack and Bury 1974, Bury et al. 1977). Vollmer et al. (1976) compared areas in which they repeatedly drove a 4-wheel-drive truck with control areas and noted differing responses of various lizard species. Side-blotched lizard, *Uta stansburiana*, and whiptail lizard, *Cnemidophorus tigris* densities were similar before, during, and after the experiment. However, counts of zebra-tailed lizards, *Callisaurus draconoides*, were much lower in the driven area.

Our small sample of male, flat-tailed horned lizards exhibited reduced rates of movement following disturbance from OHVs. This, coupled with the fact that flat-tailed horned lizards are often sighted on roads (Norris 1949, Turner and Medica 1982), may make them especially susceptible to mortality from vehicle strikes. While driving a vehicle, Wone and Beauchamp (1995) observed that the majority (86%) of the flat-tailed horned lizards they encountered fled for short distances and stopped, sometimes under shrubs, and sometimes on OHV trails. Thus, flat-tailed horned lizards may attempt to avoid OHVs, although road mortalities have been observed when lizards fail to move out of the way of oncoming traffic (Muth and Fisher[4] 1992).

Our results for activity area size were equivocal, as some increased and others decreased after the race. Turner and Medica (1982) reported that the mean home range size of 5 male, flat-tailed horned lizards, as measured with convex polygons, was 1,287 m^2 (range 804–2,112 m^2). The activity areas we observed (Table 2) were generally much larger, but we used almost twice as many recaptures as Turner and Medica (1982).

Avoiding OHV activity may not protect flat-tailed horned lizards from lethal effects. Muth and Fisher[4] (1992) observed dormant flat-tailed horned lizards at soil depths from 2.5 to 10 cm (mean = 5.6, n = 6). As motorcycle tires are capable of increasing soil density (soil compaction) to depths of 30–60 cm (Webb 1983), OHV activities may kill immobile subterranean animals (Stebbins 1995).

The consequences of moving at different rates and directions after a disturbance may be negative or positive. If these changes fail to take the animal away from the area of impact, or the movements are energetically costly, the consequences may be negative. If the movements decrease the probability of an animal being struck by an OHV, then the consequences are potentially positive. While our analysis is preliminary because of small sample size, these data are the first to suggest that OHV activity affects movement of flat-tailed horned lizards.

ACKNOWLEDGMENTS

Earlier versions of this manuscript benefited greatly from comments provided by A. Muth and M. Fisher of the University of California, Boyd Deep Canyon Desert Research Center; P. Medica of the U.S. Geological Survey, Las Vegas Field Station;

G. Wright of the Palm Springs-South Coast Resource Area of the Bureau of Land Management; and R. Lovich of San Diego State University.

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Received: 6 March 2000
Accepted: 21 June 2000

California Fish and Game 86(3):213-215 2000

OBSERVATION OF THE PRICKLY SHARK, *ECHINORHINUS COOKEI*, FROM THE OXYGEN MINIMUM ZONE IN SANTA BARBARA BASIN, CALIFORNIA

JAMES P. BARRY and NORMAN MAHER
Monterey Bay Aquarium Research Institute
7700 Sandholdt Road
Moss Landing, California 95039
e-mail: barry@mbari.org

The prickly shark, *Echinorhinus cookei*, and its congener, the bramble shark, *E. brucus*, are the only extant members of the family Echinorhinidae, a family of squaliform sharks known from temperate to tropical seas (Compagno 1984). Bramble sharks have been reported broadly in the Indian, Atlantic and western Pacific oceans, but have not been seen in the eastern Pacific. Prickly sharks have been observed throughout the Pacific, but have not been reported from the Atlantic Ocean. These uncommon sharks have been collected or observed on the continental shelf and slope, as well as in submarine canyons. We report here an observation of a prickly shark in low oxygen waters at a depth of 342 m in the Santa Barbara Basin, California, extending its previously reported bathymetric range of 18 to 280 m (Eschmeyer and Herald 1983) in the eastern North Pacific.

A single female prickly shark was observed during dive #1495 (34°22'38.3"N, 119°59'7.1"W) of the ROV *VENTANA* on 8 October 1998 during a research expedition in the Santa Barbara Basin sponsored by the Monterey Bay Aquarium Research Institute. The shark was observed for only a short time (< 1 minute). No prickly sharks were observed during 9 other ROV dives in the region during the expedition. The individual was identified as an echinorhinid by several characteristics, including the lack of an anal fin, small spiracles, posterior location of the 2 dorsal fins, and position of the 1st dorsal fin over the pelvic fins, rather than anterior to the pelvic fins, as found in squalid sharks. It was determined to be a prickly shark, based on the fine denticles covering the body and lack of large tack-like denticles that distinguish the bramble shark. The water temperature at 342 m depth was 6.8°C, salinity was 34.17‰, and oxygen concentration was 0.56 ppm. The prickly shark was either stationary or swimming slowly on or very near the sea floor as the ROV approached. The shark circled slowly near the ROV, swam toward the camera, then abruptly swam out of the light field when it contacted the camera with its snout. Total length of the shark was estimated to be about 1.75 m, based on a reference scale provided by parallel laser beams projected onto the sea floor from the ROV. This size is much smaller than the maximum reported size of about 4 m total length (Compagno 1984).

Echinorhinids are best known from continental shelf habitats, but have been reported to depths exceeding 500 m and perhaps as great as 1000 m (Melendez and Meneses 1986). In tropical regions, greater depth of occurrence for either species

of *Echinorhinus* may be related to isothermic submergence (Crow et al. 1996). Off Hawaii, the thermocline may occur as deep as 100–400 m, resulting in avoidance of these warm waters by these sharks. Alternatively, records of echinorhinids from deep (>500 m) waters in tropical to subtropical waters of the central to western Pacific may be related to the higher oxygen concentrations at these locations, relative to comparable depths in the eastern Pacific. The higher frequency of reports from continental shelf and upper slope habitats may also be related to sampling effort, as fishing effort and submersible observations are generally more widespread in shallower waters.

The stationary or sluggish swimming behavior we observed is similar to that reported from SCUBA observations of numerous prickly sharks in relatively shallow (30 m) depths near the head of Monterey Canyon (Crane and Heine 1992). Although swimming slowly over the sea floor may be a predatory search behavior, the principal prey reported for prickly sharks are fishes and invertebrates, including other sharks, octopi, squids, and crabs (Compagno 1984, Compagno and Niem 1998). Feeding on such prey should require more aggressive swimming behavior. The abundance of benthic megafauna (potential prey) was similar to that observed throughout much of the region during other ROV dives, suggesting that the shark was not in the area due to a particularly high abundance of prey. Although video records do not allow definitive determination, some sensory structures visible on the snout appear to be ampullae of Lorenzini. Such ampullae have not been reported previously in *Echinorhinus*, but their presence would suggest that prickly sharks employ electroreception in prey detection, as shown for other sharks (Kalmijn 1982).

Reduced activity (e.g., resting or sluggish swimming) may also allow prickly sharks to avoid or minimize metabolic oxygen stress in the poorly oxygenated waters deep in the Santa Barbara Basin, as well as the oxygen minimum zone over much of the eastern Pacific. The oxygen concentration tolerated by the prickly shark observed (0.56 ppm) was considerably less than is typical in shallower waters (3–6 ppm in <100 m) over most of the continental shelf. Tolerance of low oxygen levels by echinorhinids may enable them to exploit continental slope habitats that are unsuitable for sharks with higher metabolic oxygen demands.

ACKNOWLEDGMENTS

We are grateful to the Monterey Bay Aquarium Research Institute for funding this research. The crew of the R/V *PT. LOBOS* and pilots of the ROV *VENTANA* were a pleasure to work with during the Santa Barbara Basin expedition.

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Received: 10 December 1999
Accepted: 6 March 2000

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